SPACE TIME BLOCK CODING USING PHASE SHIFT KEYING

RUSESALIZA BINTI MOHAMAD ROZI

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Fakulti Kejuruteraan Elektrik
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ABSTRACT

This thesis deals with space-time block coding (STBC), one of the remarkable modulation schemes proposed for multiple antenna wireless systems providing full diversity gains. STBC is a revolutionary development for exploiting the multiple-input-multiple-output (MIMO) channel by using antenna array processing technology, which is currently stimulating considerable interest across the wireless industry. It is now adapted for use in the third generation wireless network by WCDMA and CDMA 2000 standardization bodies. The objective of this project is to evaluate the performance of the STBC deployed in wireless transmission. A communication network model for STBC is developed using Phase Shift Keying (PSK) modulation. Linear Block Codes, namely Hamming code has been used in the design criteria to provide error detection mechanism during data transmission. Based on the scheme proposed by Alamouti [4], our approach network model uses two transmit antennas and one receive antenna with a multipath Rayleigh fading introduced at the communication channel. The performance evaluation and analysis of the proposed network model using STBC has been carried out using MATLAB v6 simulation package. The performance of STBC is investigated by comparing it with Maximum-Ratio Receive Combining (MRRC) technique. Simulation results show that the use of STBC can provide diversity and have a very simple encoding and decoding algorithm. Using two transmit antennas and one receive antenna in this project provides the same diversity order as using basic MRRC technique with one transmit antenna and two receive antennas. It has been shown that the performance of the BER for STBC has improved by nearly thirty three percent compared to MRRC. From the result obtained, we can conclude that the STBC will become an important technique in the design of future wireless system.

ABSTRAK

Tesis ini akan membentangkan Pengkodan Blok Ruang-Masa (STBC), ia merupakan salah satu keistimewaan skim pemodulatan yang dicadangkan untuk sistem tanpa wayar pelbagai antenna yang dilengkapi oleh gandaan kepelbagaian penuh. Pengkodan Blok Ruang Masa ialah satu pembangunan menilai semula menggunakan saluran pelbagai keluaran pelbagai (MIMO) dengan menggunakan teknologi pemprosesan penyusunan (array) antenna, dimana baru-baru ini rangsangan diambil kira dalam industri tanpa wayar. Sekarang ia diadaptasikan dengan menggunakan generasi ke-3 rangkaian tanpa wayar oleh badan pempiawaian WCDMA dan CDMA 2000. Objektif projek ini adalah untuk menilaikan kemampuan bagi sistem Pengkodan Blok Ruang Masa yang dikira dalam penghantaran tanpa wayar. Satu model rangkaian perhubungan untuk Pengkodan Blok Ruang Masa dibina dengan menggunakan pemodulatan Penguncian Anjakan Fasa (PSK). Kod-kod Blok Lelurus atau Kod Hamming dilaksanakan dalam kriteria rekabentuk untuk mengesan ralat semasa penghantaran. Berdasarkan kepada skim 'STBC' yang dibangunkan oleh S.Alamouti, projek ini memperkenalkan model rangkaian yang menggunakan dua antena penghantaran dan satu antena penerima melalui saluran pelbagai penghapusan Rayleigh (Multipath Rayleigh Fading). Kemampuan bagi 'STBC' adalah dinilaikan dengan membandingkan ia dengan teknik Penggabungan Maksimum Nisbah Penerima (MRRC). Keputusan simulasi menunjukkan penggunaan sistem ini boleh menyediakan kepelbagaian (diversity) dan mempunyai satu contoh mudah bagi algoritma , pengkodan dan penyahkodan yang menggunakan skim dua antena penghantaran dan dua antena penerima. Daripada graf kadar bit ralat (BER) berlawanan dengan nisbah isyarat ke hingar (SNR) yang diplotkan, ia menunjukkan prestasi bagi kadar bit ralat sebanyak 33% lebih rendah berbanding dengan 'MRRC'. Daripada keputusan yang diperolehi, dapat diringkaskan bahawa Pengkodan Blok Ruang Masa menunjukkan kepentingan sesuatu teknik penting dalam merekabentuk sistem perhubungan tanpa wayar akan datang.

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LIST OF SYMBOLS

AWGN	-	Additive White Gaussian Noise
BPSK	-	Binary Phase Shift Keying
BER	-	Bit error rate
MIMO	-	Multiple Input Multiple Output
PSK	-	Phase Shift Keying
SNR	-	Signal noise ratio
STBC	-	Space Time Block Coding
STC	-	Space Time Coding
E_b	-	Transmitted signal energy
f_c	-	carrier frequency
M	-	number of receive antenna
N	-	number of transmit antenna
P_e	-	Probability of error
$r(t)$	-	received signal
$s(t)$	-	transmit signal

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CHAPTER 1

INTRODUCTION

1.1 Space-Time Coding

Recently, wireless communication system has become a very popular method for transmission. Without using a fixed medium such as fiber optic and copper cable for signal/data transmission, wireless communication offer easier implementation while reducing cost for infrastructure works. However, in most situations, the wireless communication channel suffers attenuation due to destructive addition of multipaths in the propagation media. It also suffers interference from the other users. The channels statistic is significantly often Rayleigh which makes it difficult for the receiver to reliably determine the transmitted signal unless some less attenuated replica of the signal is provided to the receiver [1]. In current wireless communication system, diversity technique has been introduced to overcome the problems. One novel approach is to use antenna diversity, which used multiple transmit antennas, namely called Space-Time Coding (STC).

STC is a new transmits diversity technique that introduces redundancy in the transmitted signal in both the spatial and the time domain. STC is a diversity technique that combines time and spatial (space) diversity. Space time coding coordinates the transmissions from diversity antennas so that a receiver with a single antenna can still obtain diversity. Such coding schemes promise enhanced performance in terms of power efficiency, good error performance at low SNR and spectral efficiency due to the exploitation of the inherent parallelism and diversity within the Multiple Input Multiple Output (MIMO) channel [2].

Diversity suggests that there is more than one transmission path or method of transmission available between a transmitter and a receiver. When there is more than one transmission path or method of transmission available the system can select the path or method that produces the high quality receive signal. The purpose of diversity is to overcome the poor performance of transmission over wireless communication.

STC becomes a hot topic of intensive research in recent years. The concept of STC was first proposed by V.Tarokh using trellis-based space-time codes [3]. Later, the space-time block code (STBC) for two transmit antennas was invented by S.Alamouti [4]. After that, more research has been done to discover the advantages of STC in many ways. The applications of STC and transmit diversity has received great attention. The advantages of these techniques are:

i. Improved BER and system capacity
ii. Improved data rate and reuse factor
iii. Improved system coverage and bandwidth efficiency
iv. Reduced handset complexity

As mentioned above, the STC and transmit diversity technique can improve system coverage and bandwidth efficiency and also reduced handset complexity. With this kind of advantages, STC and transmit diversity can be employed in wireless communications system such as IS-54/136 and GSM (TDMA), IS-95 (CDMA), and third generation W-CDMA and CDMA 2000 [5]. Even in forthcoming 4^{th} generation system, these techniques will still be considered.

Space-time codes are a highly bandwidth-efficient approach to signaling within wireless communication. It takes the advantages of the spatial dimension by transmitting a number of data streams using multiple co-located antennas. There are various approaches to the coding structures, including space-time turbo codes and also layered architecture. The issue in all these various coding structures is the exploitation of multipath effects in order to achieve very high spectral efficiencies. The spectral efficiencies of traditional wireless system range between 1 - 5 bps/sec/Hz. But by using space-time codes techniques spectral efficiencies of 20 - 4-bps/sec/Hz have been possible. Hence, space-time coding enables an increase in capacity by an order of magnitude. This is the main reason why space-time codes have been included in the standards for the third generation wireless communication system. This is also why space-time codes in a great demand by individuals within industry and academic sector [6].

1.2 Problem Statement

In most situations, the wireless channel suffers attenuation due to destructive addition of multipaths in the propagation media and to interference from the other users. The channel statistic is significantly often Rayleigh which makes it difficult for the receiver to reliably determine the transmitted signal unless some less attenuated replica of the signal is provided to the receiver. This technique is called diversity, which can be provided using temporal, frequency, polarization, and spatial resources.

In wireless transmission, the system might use diversity not at the receiver but also use at the transmitter. One of the ways to provide the diversity is through time interleaving. Time interleaving is use in time or temporal diversity technique in space-time coding. Time diversity is a process by which a signal is repeated any number of times over multiple time slots. Time interleaving together with error correction coding can provide diversity improvement.

1.3 Objective Of Study

The objective of this project is to evaluate the performance of space-time coding on a wireless communication network model. In this project, the focus of the work is on the use of space-time block coding technique (STBC) on the network using Phase Shift Keying (PSK) as the modulation technique. The communication network model will also use the transmit diversity technique which employ multiple antennas at the transmitter side.

1.4 Scope of work

The scope of work includes developing a mathematical simulation model consisting of a transmitter, channel and receiver using Matlab version 6.1 environment. The transmitter consists of an STC coder, a modulator. The receiver consists of a demodulator, an STC decoder. The performance of the proposed STC is evaluated using the network model developed. A coding technique based on Hamming Code will be used to represent a block code while the modulation technique is based on PSK. Simulation is carried out to evaluate the performance of BER (bit error rate) versus SNR by using STBC and compared with MRRC

1.5 Outline of Thesis

This thesis focuses on the theory and simulation of the STBC system. It is arranged into five chapters. The first chapter defines the introduction including the main objective of the project. Chapter II introduces the communication network system based on the basic of communication network model such as explanation about space-time coding and MIMO channel are presented. The theory of space-time block code is also presented in this chapter. Chapter III will briefly discuss the mathematical simulation network model, the explanation about Matlab, development of STBC and development of Hamming code. The test results and discussion obtained for STBC using PSK are presented in chapter IV. The performance of bit error rate is also discussed in this chapter. Finally, the main conclusion drawn from this project is given in chapter V along with the recommendation for the future work.

CHAPTER II

COMMUNICATION NETWORK SYSTEM

2.1 Basic Communication Model

A basic communication system consists of a transmitter, a channel and a receiver. Figure 2.1 shows the block diagram of a basic communication system. Three basic signal processing are identified as source coding, channel coding and modulation.

In source coding, the encoder maps the signal generated at the source output into another signal. The mapping is one to one, and the objective is to eliminate or reduce redundancy so as to provide an efficient representation of the source output. The source decoder simply performs the inverse mapping and thereby delivers to the user destination a reproduction of the original source output.

In channel coding, the objective is for the encoder to map the incoming signal into a channel input and for the decoder to map the channel output into an output signal in such a way that the effect of channel noise is minimized. The combined of the channel encoder and decoder is to provide for reliable communication over a noisy channel. In the source coding, we remove redundancy, whereas in the channel coding we introduce controlled redundancy.

In the receiver, the channel coding is performed first, followed by source decoding. Whichever combination used, the result shows improvement in system performance achieved at the cost of increased circuit complexity. The detector performs demodulation, thereby producing a signal that follows the time variations in the channel encoder output.

The combination of modulator, channel and detector on the dashed rectangle shown in Figure 2.1, is called a discrete function.

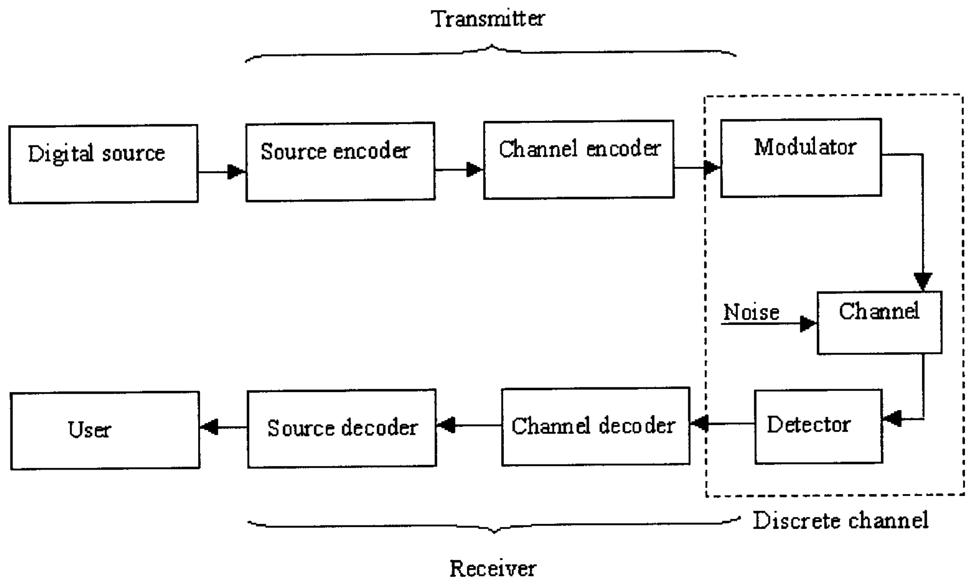
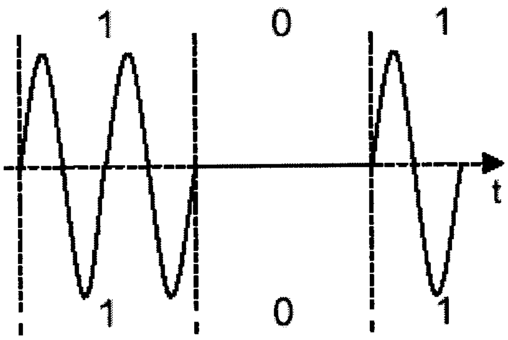


Figure 2.1 : Basic Communication System

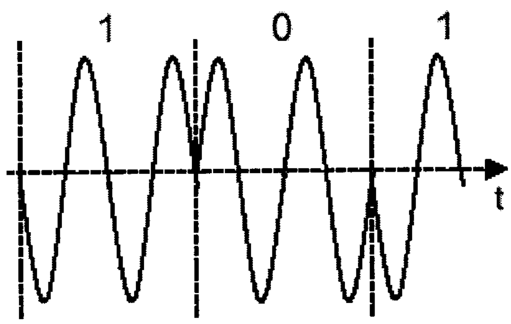
The purpose of the modulation is to provide an efficient transmission of the signal over the channel. The modulator operates by keying shifts in the amplitude, frequency or phase of a sinusoidal carrier wave to the channel encoder output. The modulation technique is referred as amplitude shift keying, frequency shift keying or phase shift keying respectively.

Modulation is the process by which some characteristics of a carrier are varied by a modulating wave. The modulating wave consists of binary data. The carrier to use is a sinusoidal wave. With a sinusoidal carrier, the feature that is used by the modulator to distinguish one signal from another change the amplitude, frequency or phase of the carrier. This modulation process is Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK) and Phase Shift Keying (PSK) as shown in Figure 2.2. From the figure we can see that PSK and FSK signals have a constant envelope. This feature makes them impervious to amplitude nonlinearities. The waveform shown in Figure 2.2, a single feature of the carrier (amplitude, phase or frequency) undergoes modulation.

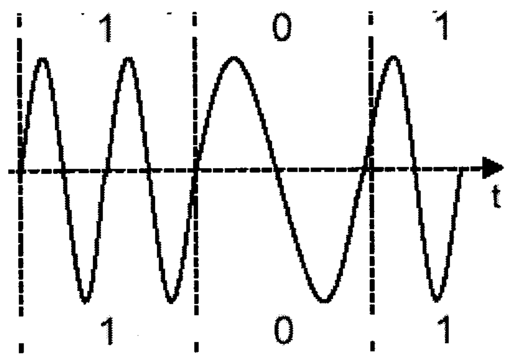
To perform demodulation at the receiver, we have coherent and noncoherent detection. The form of coherent detection is the exact replicas of the possible arriving signals that are available at the receiver. Coherent detection is performed by cross-correlating the receive signal with each one of the replicas.



(a) ASK



(b) PSK



(c) FSK

Figure 2.2 : Waveforms for a) ASK, b) PSK, c) FSK

2.2 Various Coding Techniques

Channel coding is a type of digital signal processing that improves data reliability by introducing a known structure into a data sequence prior to transmission or storage. This structure enables a receiving system to detect and possibly correct errors caused by corruption from the channel and the receiver. As the name implies, this coding technique enables the decoder to correct errors without requesting retransmission of the original information [19]. There are several types of coding schemes such as Algebraic codes, Convolutional codes and Turbo codes. This section will present the overview of the above codes.

In a communication system that employs forward error-correction coding, a digital information source sends a data sequence to an encoder. The encoder inserts redundant (or *parity*) bits, thereby outputting a longer sequence of code bits, called a codeword. Such codeword can then be transmitted to a receiver, which uses a suitable decoder to extract the original data sequence.

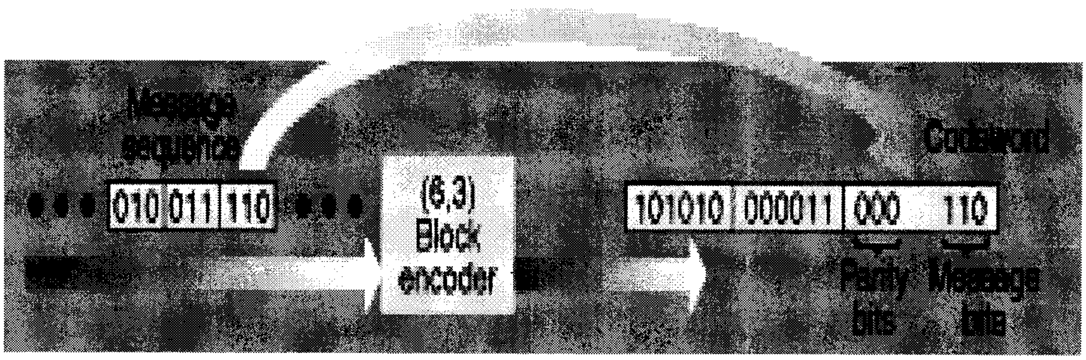


Figure 2.3: The example of (6,30 algebraic encoder

The above diagram in Figure 2.3 is an example of a (6, 3) algebraic encoder that produces a six-bit codeword for every three-bit message sequence. In this example, each six-bit output codeword is composed of the original three-bit message sequence and a three-bit parity sequence. This codeword format is known as *systematic*.

Codes that introduce a large measure of redundancy convey relatively little information per each individual code bit. This is an advantage as it reduces the likelihood that all of the original data will be wiped out during a single transmission. On the other hand, the addition of parity bits will generally increase transmission bandwidth requirements or message delay (or both).

Algebraic coding (also known as block coding) was the only type of forward error-correction coding in use when Claude Shannon published his seminal *Mathematical Theory of Communication* in 1948. With this technique, the encoder intersperses parity bits into the data sequence using a particular algebraic algorithm. On the receiving end, the decoder applies an inverse of the algebraic algorithm to identify and correct any errors caused by channel corruption.

Another types of coding known as convolutional coding, was first introduced in 1955. Convolutional codes process the incoming bits in streams rather than in blocks. The paramount feature of such codes is that the encoding of any bit is strongly influenced by the bits that preceded it (that is, the memory of past bits). A convolutional decoder takes into account such memory when trying to estimate the most likely sequence of data that produced the received sequence of code bits. Historically, the first type of convolutional decoding, known as sequential decoding, used a systematic procedure to search for a good estimate of the message sequence; however, such procedures require a great deal of memory, and typically suffer from buffer overflow and nongraceful degradation.

In 1967, Andrew Viterbi developed a decoding technique that since has become the standard for decoding convolutional codes. At each bit-interval, the Viterbi decoding algorithm compares the actual received code bits with the code bits that might have been generated for each possible memory-state transition. It chooses, based on metrics of similarity, the most likely sequence within a specific time frame. The Viterbi decoding algorithm requires less memory than sequential decoding because unlikely sequences are dismissed early, leaving a relatively small number of candidate sequences that need to be stored.

Some types of algebraic coding are most effective in combating "bursty" errors (errors that arrive in bursts). Convolutional coding is generally more robust when faced with random errors or white noise; however, any decoding errors occurring in the convolutional decoder are likely to occur in bursts. In 1974, Joseph Odenwalder combined these two coding techniques to form a concatenated code. In this arrangement, the encoder linked together an algebraic code followed by a convolutional code. The decoder, a mirror image of the encoding operation, consisted of a convolutional decoder followed by an algebraic decoder. Thus, any bursty errors resulting from the convolutional decoder could be effectively corrected by the algebraic decoder. Performance was further enhanced by using an interleaver between the two encoding stages to mitigate any bursts that might be too long for the algebraic decoder to handle.

In 1993, Claude Berrou and his associates developed the turbo code, the most powerful forward error-correction code. Using the turbo code, communication systems can approach the theoretical limit of channel capacity, as characterized by the so-called Shannon Limit, which had been considered unreachable for more than four decades.

Turbo Coding is one of the requirements of a turbo coder-decoder (or *codec*) configuration is that the encoder must include some arrangement of at least two component encoders. Although each component encoder may employ algebraic coding or convolutional coding, the overall encoder can be considered a block encoder because data are processed in blocks. The size of these blocks is dictated by the length of the interleaver that separates each component encoder.

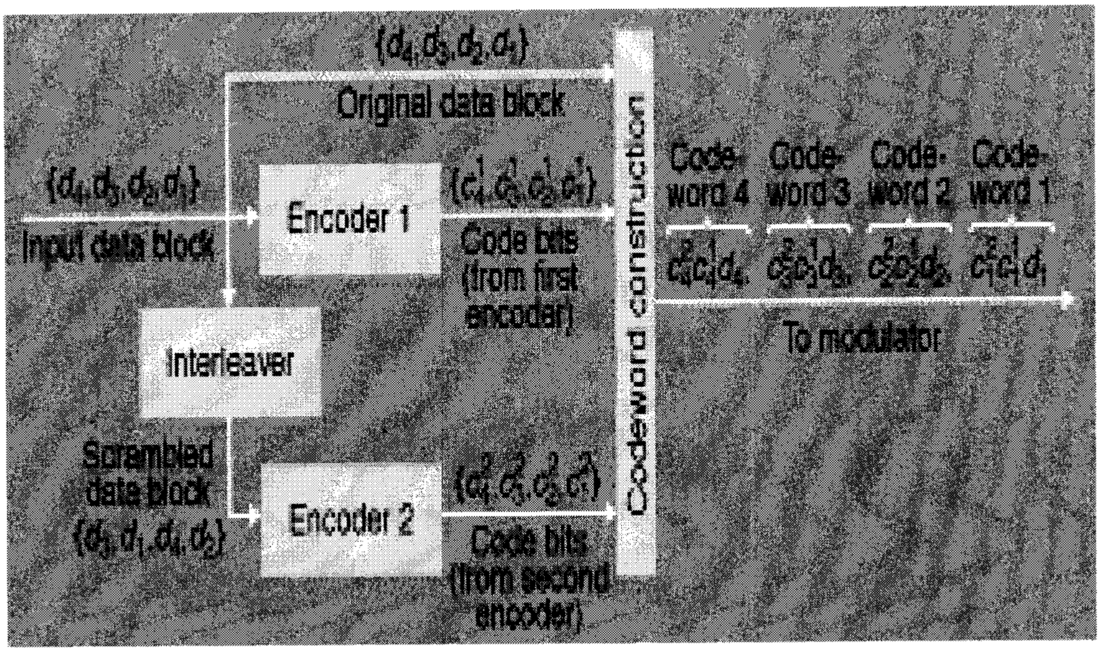


Figure 2.4 : The example of Turbo Encoder

Above in Figure 2.4 is an example of a turbo encoder using parallel concatenated component codes (the most commonly implemented configuration). Although the figure shows a block size of four bits for discussion purposes, typical block sizes are on the order of hundreds or thousands of bits. Bit times are indicated by subscripts. The figure represents a rate-1/3 turbo encoder (that is, one data bit produces a three-bit codeword), but other rates are possible with this identical configuration by the careful elimination of selected code bits.

The interleaver in a turbo encoder serves a different purpose than interleavers used by other parts of a communication system. Standard interleavers scramble code bits among multiple blocks so that they are not contiguous when transmitted; as a result, any bursty errors caused by channel corruption are transformed, or spread out, into more-random errors after deinterleaving. The interleaver in a turbo encoder, on the other hand, is designed so that the second encoder gets an interleaved version of the same data block that went into the first encoder; thus, the second encoder generates an independent set of code bits. Doing so provides diversity to the coded sequence being transmitted. Although any interleaving pattern can be adopted, different patterns can result in significant differences in the bit-error rate; therefore, the interleaver design contributes significantly to the overall error performance of the turbo-code system. The turbo codec must have as many component decoders on the receiving end as component encoders on the transmitting end. These decoders are concatenated in serial fashion and are joined by a series of interleavers and deinterleavers in a feedback loop.

In a typical decoding operation, the first decoder generates statistical information based on the data received from the first component encoder. This information is then fed to the second decoder, which processes it along with the data received from the second component encoder. After decoding, the improved and updated statistical information is fed back to the first decoder, which starts the process again. This process typically continues for six to ten iterations for each block of data, at which point a switch is triggered and the actual data estimates are produced.

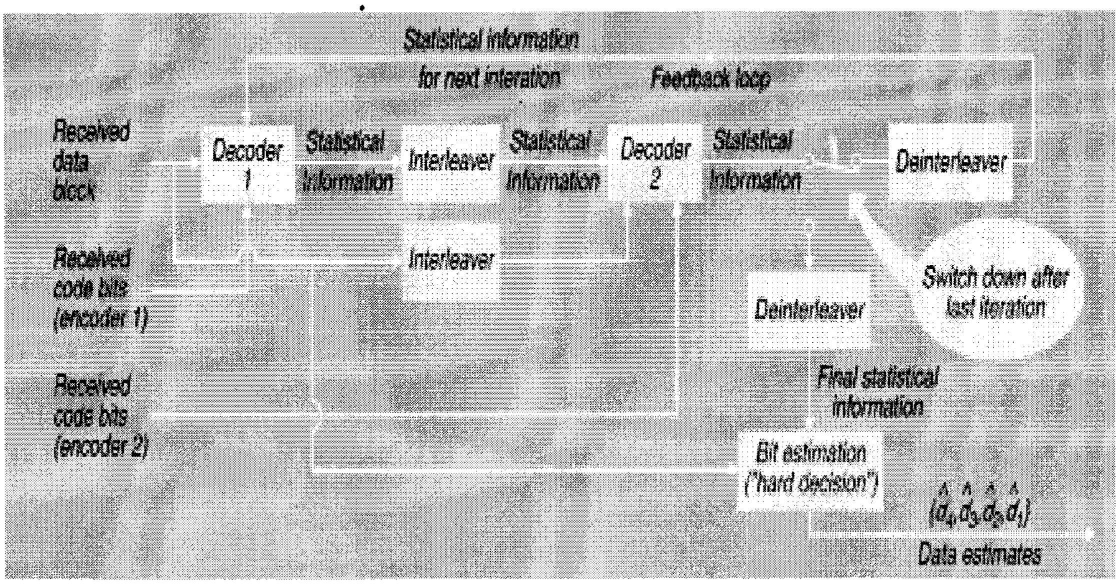


Figure 2.5: The example of Turbo Decoder

Turbo decoders have an iterative structure, composed of as many component decoders as there are component encoders, concatenated in a serial fashion. The interleavers and deinterleavers are used to ensure the correct ordering among the various types of information processed.

In the iterative decoding process, turbo codes can achieve a bit-error rate that approaches the Shannon limit. For example, at a desired bit-error rate of 10^{-6}, convolutional codes can typically provide a 5.5-decibel improvement (72 percent power savings) and concatenated codes a 7.75-decibel improvement (83 percent power savings) over an uncoded system. Using a turbo code, an additional 2.25-decibel improvement over the concatenated code can be attained, resulting in a total coding gain of 10 decibels (90 percent power savings) compared with the uncoded system. For a rate-1/2 turbo-coded system, the error performance comes within about 1 decibel of the Shannon limit. Turbo code's performance is sensitive to elements in the code's structure (such as component code configuration and interleaving pattern).

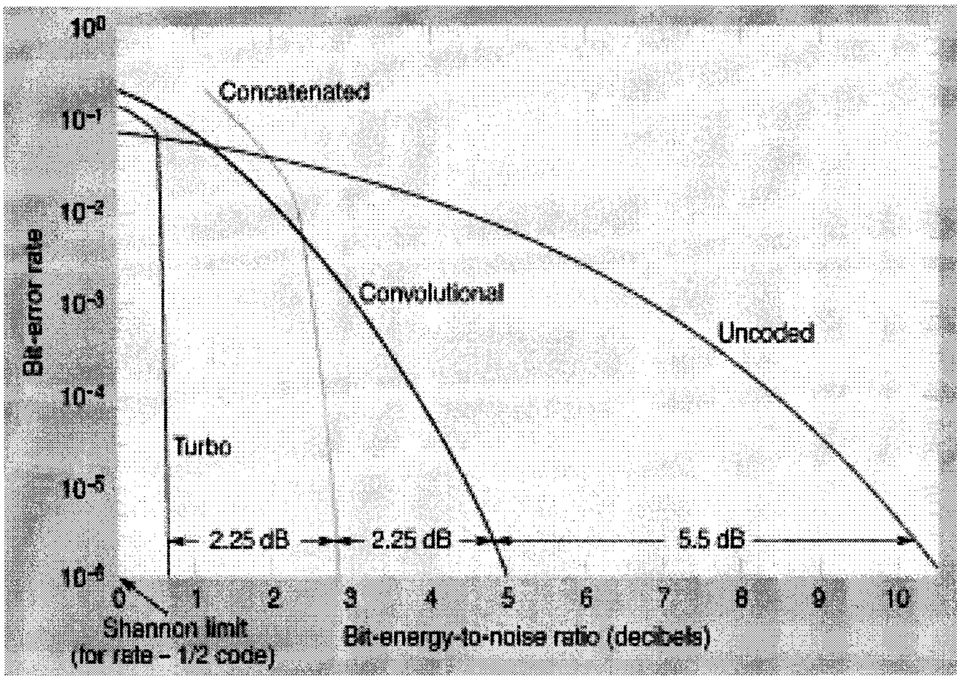


Figure 2.6: The BER of Turbo, Convolutional and Concatenated Coding

The bit-error rate of a rate-1/2 turbo coded system after 10 iterations as compared with systems that use no coding, convolutional coding, and concatenated coding.

In this example, at a desired bit-error rate of 10^{-6}, the use of convolutional and concatenated codes provides a 5.5-decibel (72 percent power savings) and 7.75-decibel (83 percent power savings) respective improvement compared with the uncoded system. Here, the use of a turbo code imparts an additional 2.25-decibel improvement compared with the concatenated code, resulting in a total coding gain of 10 decibels (90 percent power savings) compared with the uncoded system. With the use of a rate-1/2 turbo code, system error performance can approach levels within about 1 decibel of the Shannon limit.

Channel coding represents the most efficient, economical, and predictable way of improving the reliability of transmitted or stored data. As concerns over spectrum management and bandwidth efficiency increase, the ability to maximize channel capacity without sacrificing data reliability becomes all the more important.

2.3 Diversity Technique

The most adverse propagation effect from which wireless communications systems suffer is the multipath fading. A popular method to mitigate the effects of multipath fading is diversity technique. Diversity is a technique which is more than one antenna transmission path or method of transmission available between a transmitter and a receiver. The purpose of diversity is to increase the reliability of the system by increasing its availability and to mitigate the poor performance of transmission over wireless channel [9].

2.3.1 Spatial Diversity

The spatial diversity method achieves independent channels by receiving or transmitting the same signal on different antennas, separated by some internal distance. The classical approach is to use multiple antennas at the receiver and to use some combination technique to improve capacity as shown in Figure 2.7 [9]. Thus, space-time coding achieves spatial diversity by using multiple transmit antennas.

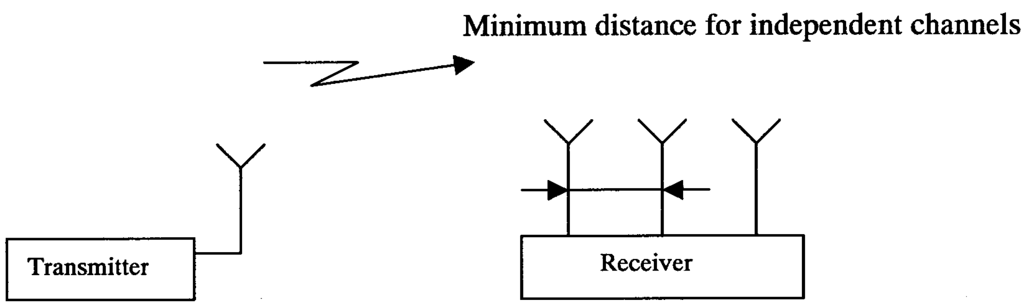


Figure 2.7: Spatial diversity

2.3.2 Time Diversity

For time diversity the information is sent in different time slots, separated some time, Δt, sufficient for independent channels, as shown in Figure 2.8. In GSM, time diversity gain is achieved by introducing an error correcting code and interleaving [6]. A transmission sequence, with error correcting code, is sensitive to burst errors due to dependencies in the sequence and by interleaving, this dependency is spread in time thus achieving time diversity [9].

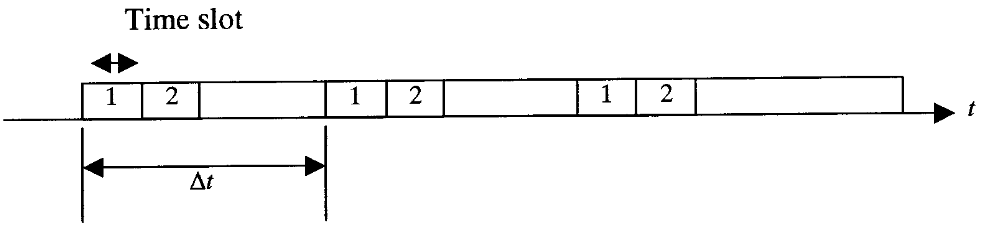


Figure 2.8 : Time diversity

2.3.3 Frequency Diversity

With frequency diversity the signal is transmitted with several frequency (see Figure 2.9).

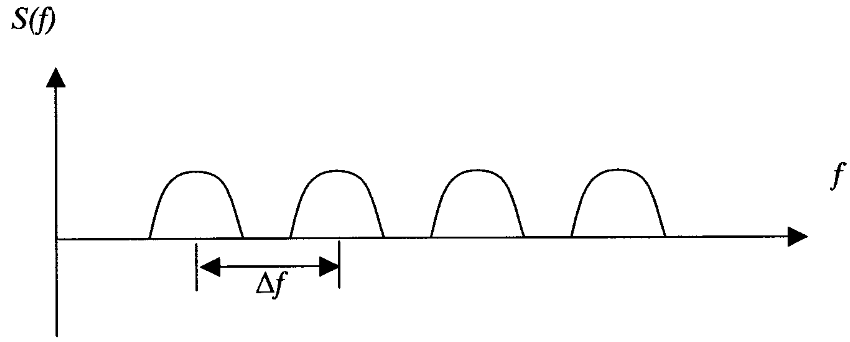


Figure 2.9 : Frequency diversity

For the channels to be independent the frequencies must be separated with a certain frequency band Δf.

2.4 Space Time Block Coding (STBC)

The basic space-time block codes is initiated by Alamouti [4] and generalized by Tarokh, [1]. The main idea behind STBCs is to linearly and orthogonally encode a signal stream and simultaneously transmit it through a system of uncorrelated wireless channels. The system model of a generic space-time is depicted in Figure 2.10. Due to the orthogonal encoding, the signal stream can be extracted at the receiving end. Due to the linear decoding, the decoding is linear and thus very simple as well. STBCs have the following characteristics :

i. They offer diversity gain and no coding gain
ii. They shift complexity from the receiver to the transmitter
iii. They are designed in dependency of the number of transmit antennas
iv. They offer diversity gain for any number of receive antennas
v. They require a set of uncorrelated MIMO channels
vi. They require a quasi-static channel for the duration of each signal block

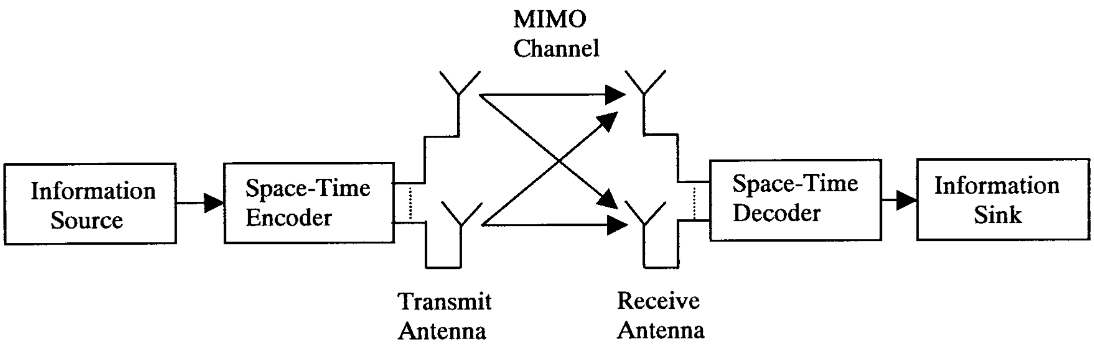


Figure 2.10 : Space-Time Encoder and Decoder operating over an N x M MIMO Channel

In wireless communication the multipath propagation of the signal results in a fading channel. Implementing diversity into the system can achieve robustness against fading [10]. Space-time coding is a technique that uses the combination of spatial and time diversity.

The transmission model for the space-time block code system is taken from [1] and the rest of this section will define that model. In a space time block coding system there are n transmit antennas and m receive antennas. At a given time slot *t*, n signals *st i* = 1,2,... .n, are sent simultaneously from the *n* transmit antennas. A block diagram of the transmission side of the system can be seen in Figure 2.11. The signal received at antenna *j* during time *t* is

$$r_t^j = \sum_{i=1}^{n} \alpha_{i,j} s_t^i + n_t^j \tag{2.1}$$

Where $\alpha_{i,j}$ is the path gain between transmit antenna *i* and receive antenna *j*, and n_t^j is the noise at receive antenna j. The channel is assumed to undergo multipath fading and the fading is independent between different transmit antennas. The path gains are considered to be independent samples of a complex Gaussian distribution with a variance of 0.5 per real dimension. The noise at the receiver is independent from the path gains and in the form of additive Gaussian noise with mean of zero and a variance equal to n/(2*SNR), where n is the number of transmit antennas and SNR is ratio, not in dB [11].

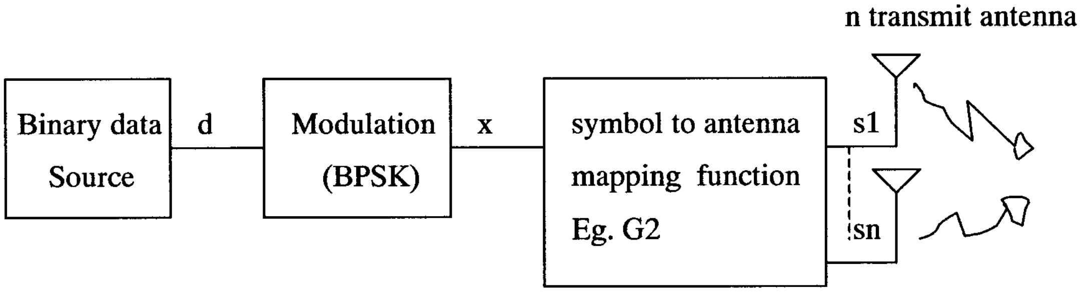


Figure 2.11 : Transmission side of Space Time Block Code system

The average energy is normalized to be unity for each symbol leaving each of the n transmitting antennas. This gives the energy of the received signal as n and SNR is measured at the receiver. The decoding for this system is rather simple and consists of minimizing the following metric,

$$\sum_{t=1}^{l} \sum_{j=1}^{m} \left| r_t^{\,j} - \sum_{i=1}^{n} \alpha_{i,j} s_t^{\,i} \right|^* \tag{2.2}$$

over all possible combinations of transmitter symbols. A block diagram of the receiving side of this system can be seen in Figure 2.12.

The encoding process is done based on the data rate the system requires. There is some signal constellation, used for modulation, which maps binary data to real or complex symbols. If there are 2^b symbols in the signal constellation, then k x b bits will be brought in to the modulator at one time slot. These k x b bits will be used to select k symbols that will be sent out over n transmit antennas simultaneously.

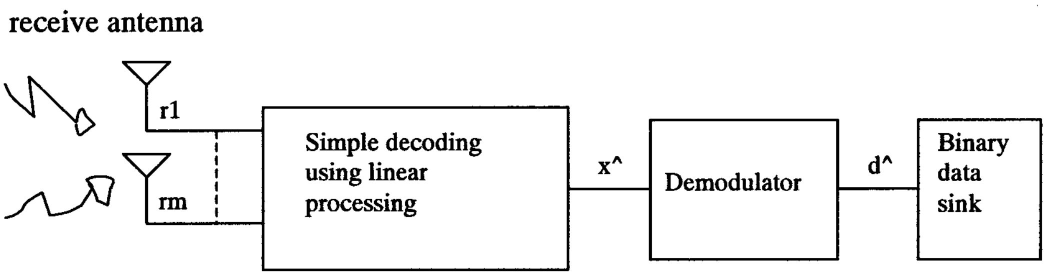


Figure 2.12 : Receiving side of Space Time Block Code system

The rate of transmission is

$$R = \frac{k}{p} \tag{2.3}$$

Where k is the number of symbols that will have to be decoded and p is the number of time slots it takes to transmit all the symbols. The notation denoting the process by which modulation symbols are mapped to different antennas is a simple p x n matrix. An example is the encoder matrix

$$G_2 = \begin{pmatrix} s1 & s2 \\ -s2^* & s1^* \end{pmatrix}$$

The *ith* row determines the symbols transmitted in time slot *i*, and the *jth* column determines the symbols transmitted from antenna j over all time slots. Several other encoder matrices were developed by V.Tarokh for various numbers of transmit antennas. The rate one half matrix used for three antennas is

$$G3 = \begin{pmatrix} s1 & s2 & s3 \\ -s2 & s1 & -s4 \\ -s3 & s4 & s1 \\ -s4 & -s3 & s2 \\ s1^* & s2^* & s3^* \\ -s2^* & s1^* & -s4^* \\ -s3^* & s4^* & s1^* \\ -s4^* & -s3^* & s2^* \end{pmatrix}$$

There are several others for three and four transmit antennas. The decoding of the space-time block code is performed by minimizing the metric shown in equation (2.1) above. However, this can be broken down into a simpler form where the metrics can be separated into several equations, each dependent only on a single transmitted symbol. For the specific case of the code defined G2, the metric can be decomposed into two simpler equations. Each one needs only to be evaluated over the possible values that a single symbol can take on, rather over combinations of symbols. The two equations for this case can be derived as follows:

There are two time slots over which signals will be received at each receive antenna generating two received signals r_1^j and r_2^j . These signals can be shown to be

$$
\begin{aligned}
r_1^j &= \alpha_{1,j} s_1 + \alpha_{2,j} + n_1^j \\
r_2^j &= -\alpha_{1,j} s_2^* + \alpha_{2,j} s_1^* + n_2^j
\end{aligned}
\qquad (2.4)
$$

This can be shown in matrix form to be

$$
r^j = \begin{bmatrix} r_1^j \\ \left(r_2^j\right)^* \end{bmatrix} = \begin{pmatrix} \alpha_{1,j} \alpha_{2,j} \\ \alpha_{2,j,}^* \; - \alpha_1^* \end{pmatrix} \begin{pmatrix} s_1 \\ s_2 \end{pmatrix} + \begin{pmatrix} n_1^j \\ \left(n_2^j\right)^* \end{pmatrix} \qquad (2.5)
$$

where, for convenience, we have conjugated the equation for r_2^j so that the signals s_1 and s_2 do not need to be conjugated.

If we take the two received signals as shown in equation (2.3) and substitute into equation (2.2) then we have the new decision metric

$$
\sum_{j=1}^{M}\left(\left| r_1 - \alpha_1 s_1 - \alpha_2 s_2 \right|^2 + \left| r_2 + \alpha_1 s_2^* - \alpha_2 s_1^* \right|^* \right) \qquad (2.6)
$$

Next we can use the identity

$$
|\xi|^2 = \xi \mathrm{X} \xi^* \qquad (2.7)
$$

to further expand the previous metric into the following metrics which can be evaluated separately in order to simplify the decoding structure.

$$\left|\left[\sum_{j=1}^{m}\left(r_1^j\alpha_{1,j}^* + \left(r_2^j\right)^*\alpha_{2,1}\right)\right] - s_1\right|^2 + \left(-1 + \sum_{j=1}^{m}\sum_{i=1}^{2}\left|\alpha_{i,j}\right|^2\right)\left|s_1\right|^2 \qquad (2.8)$$

$$\left|\left[\sum_{j=1}^{m}\left(r_1^j\alpha_{2,j}^* - \left(r_2^j\right)^*\alpha_{1,j}\right)\right] - s_2\right|^2 + \left(-1 + \sum_{j=1}^{m}\sum_{i=1}^{2}\left|\alpha_{i,j}\right|^2\right)\left|s_2\right|^2 \qquad (2.9)$$

The above two equations are not complex and can be readily implemented. This is the benefit of space-time block codes over the trellis based space-time codes, they provide maximum diversity gain with little complexity at the receiver.

2.5 Signals Combination Methods

For optimal performance the received signals must be combined in a correct way. The basic combination schemes are different in complexity and therefore naturally different in performance. The combination method is independent of the used diversity (time, frequency or spatial). Therefore the different received signals are denoted as different branches, where each branch can be a time slot, an antenna or a frequency. The four basic combination schemes are:

1) Selection diversity. Simply chooses the branch with the highest SNR of all received branches.
2) Switched diversity.
3) Maximal-ratio receive combining (MRRC). Combines all branches. All the branches is weighted with a gain factor before the combination.
4) Equal gain combining, combines all the branches as maximal ratio receive combining except for the weight factors before combination.

Maximal ratio receive combining maximizes the SNR of the combined signal but with the drawback of being the most complex of the four. The complexity is due to the fact that the weight factors must be estimated by measuring the SNR for each branch. The signals must also be cophased before combination. Cophasing produces signals with the same phase shift, which is necessary before combining.

2.5.1 Maximal-Ratio Receive Combining (MRRC) Scheme

Figure 2.13 demonstrates a baseband model of a two branch maximum ratio receive combiner (MRRC). We denote the transmitted signal at a given time instant, s_0 where $s_0 \in \{-1,1\}$. The complex base band representation of the channel from transmitter antenna zero to receive antenna zero is denoted h_0 and corresponding channel for receive antenna one h_1, where

$$
\begin{aligned}
h_0 &= \alpha_0 e^{j\theta_0} \\
h_1 &= \alpha_1 e^{j\theta_1}
\end{aligned}
\tag{2.10}
$$

After the channel, noise have been added to the received signal and the received signal can be written

$$
\begin{aligned}
r_0 &= s_0 h_0 + n_0 \\
r_1 &= s_0 h_1 + n_1
\end{aligned}
\tag{2.11}
$$

where n_0 and n_1 are independent complex noise. It's assumed that n_0 and n_1 are Gaussian distributed.

The Euclidean distance between two signals is denoted with $d^2(x,y)$ where

$$d^2(x,y) = (x-y)(x^* - y^*) \tag{2.12}$$

where * denotes the complex conjugate. Then the maximum likelihood detector *I* the receiver chooses s_i if

$$d^2(r_0,h_0s_i) + d^2(r_1,h_1s_i) \le d^2(r_0,h_0s_k) + d^2(r_1,h_1s_k), \forall_i \neq k \tag{2.13}$$

The combining scheme for the MRRC in Figure 2.13 is as follows:

$$\begin{aligned}\hat{s} &= h_0 * r_0 + h_1 * r_1 \\ &= h_0 * (h_0 s_0 + n_0) + h_1 * (h_1 s_0 * n_1) \\ &= (\alpha_0{}^2 + \alpha_1{}^2) s_0 + h_0 * n_0 + h_1 * n_1\end{aligned} \tag{2.14}$$

The cophasing and weighting factors, discussed in section 2.5 is in equation 2.14 represented by h_0* for branch (antenna) zero and h_1* for branch (antenna) one. Using equation 2.12, 2.13 and 2.14 and the fact that the signals have equal energy constellation the decision rule can be simplified to:

$$d^2(\hat{s}_0, s_i) \le d^2(\hat{s}_0, s_k), \forall_i \neq k \tag{2.15}$$

where *i* is the integer for antenna zero and *k* is the integer for antenna one. Which is, i = 1,2,3,... ... .*and* k = 1,2,3,... ... .integers.

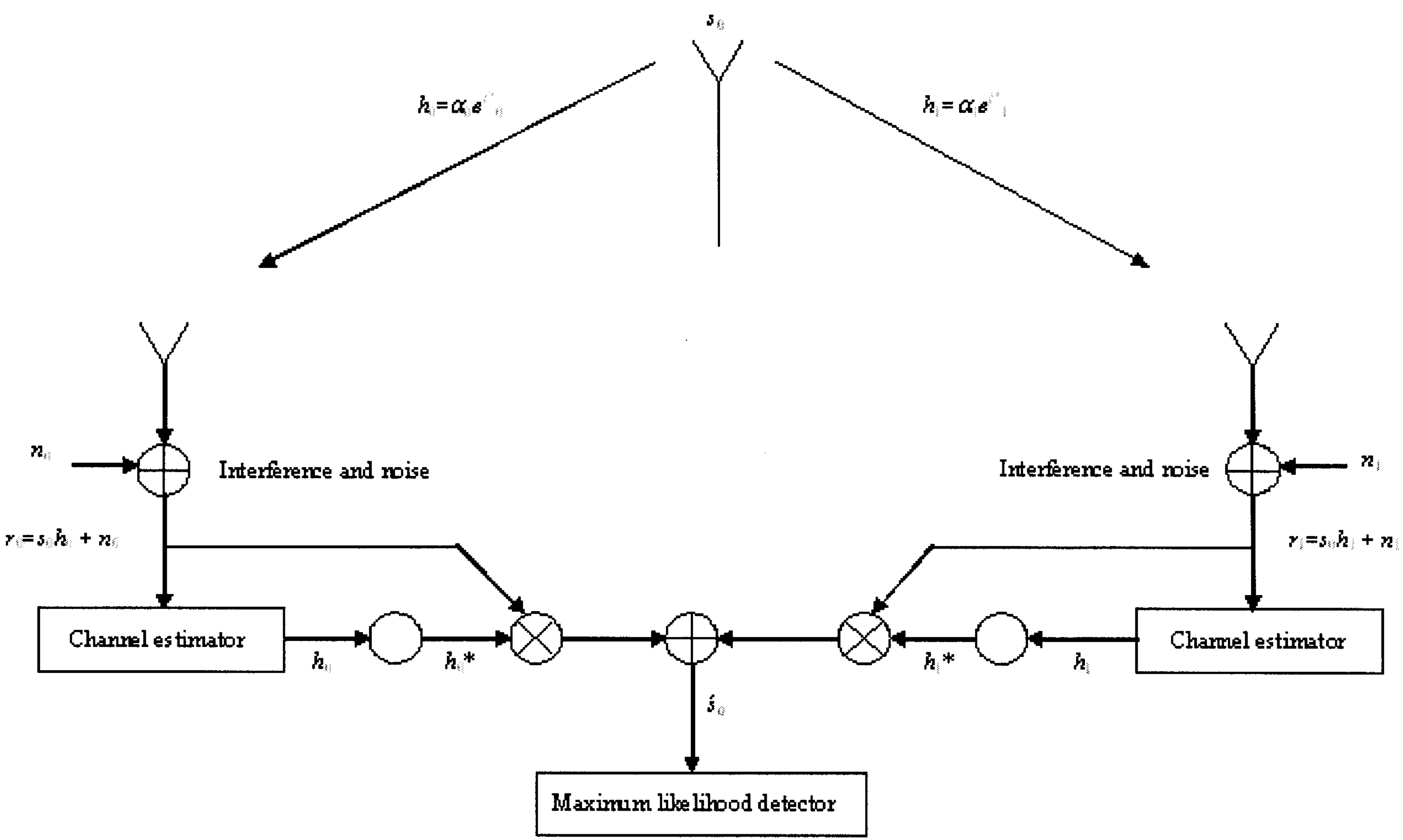


Figure 2.9 : Maximum-ratio receive combining

2.5.2 Transmit diversity scheme proposed by Alamouti

This following section will show that the new transmit diversity scheme proposed by Alamouti [4], with two transmit antennas, is displayed in Figure 2.14. With the new algorithm, two signals s_0 and s_1 are transmitted at a given time instant from antenna zero and antenna one, respectively. At the next symbol period, s_0* is transmitted from antenna one and $-s_1$* is transmitted from antenna zero. The encoding described implies the designation space-time code. The channels can be modeled as multiplicative complex time varying distortions $h_0(t)$ and $h_1(t)$. If the fading is assumed be constant over a symbol period, we can write:

$$
\begin{aligned}
h_0(t) &= h_0(t+T) = \alpha_0 e^{j\theta_0} \\
h_1(t) &= h_1(t+T) = \alpha_1 e^{j\theta_1}
\end{aligned}
\tag{2.16}
$$

where T is the symbol period. Now, the received signal can be written as,

$$
\begin{aligned}
r_0 &= r(t) = h_0 s_0 + h_1 s_1 + n_0 \\
r_1 &= r(t+T) = -h_0 s_1 * + h_1 s_0 * + n_1
\end{aligned}
\tag{2.17}
$$

where n_0 and n_1 are the same complex noise as in the MRRC description. The combiner in Figure 2.14, which is different from the one in the MRRC, combines the received signal to the following expressions:

$$
\begin{aligned}
\hat{s}_0 &= h_0 * r_0 + h_1 r_1 * \\
\hat{s}_1 &= h_1 * r_0 - h_0 r_1 *
\end{aligned}
\tag{2.18}
$$

Using equation 2.16, 2.17 and 2.18 we get,

$$\hat{s}_0 = (\alpha_0{}^2 + \alpha_1{}^2)s_0 + h_0 * n_0 + h_1 n_1 *$$

$$\hat{s}_1 = (\alpha_0{}^2 + \alpha_1{}^2)s_1 + h_0 n_1 * + h_1 * n_0 \tag{2.19}$$

The combined signals in equation 2.19 is equivalent to the one in the two branch MRRC in equation 2.14. The only difference is phase rotation of the noise but this will not influence the performance. Thus the diversity gain is the same as for MRRC. This technique can be easily generalized to two transmit and M receive antennas [1] [25].

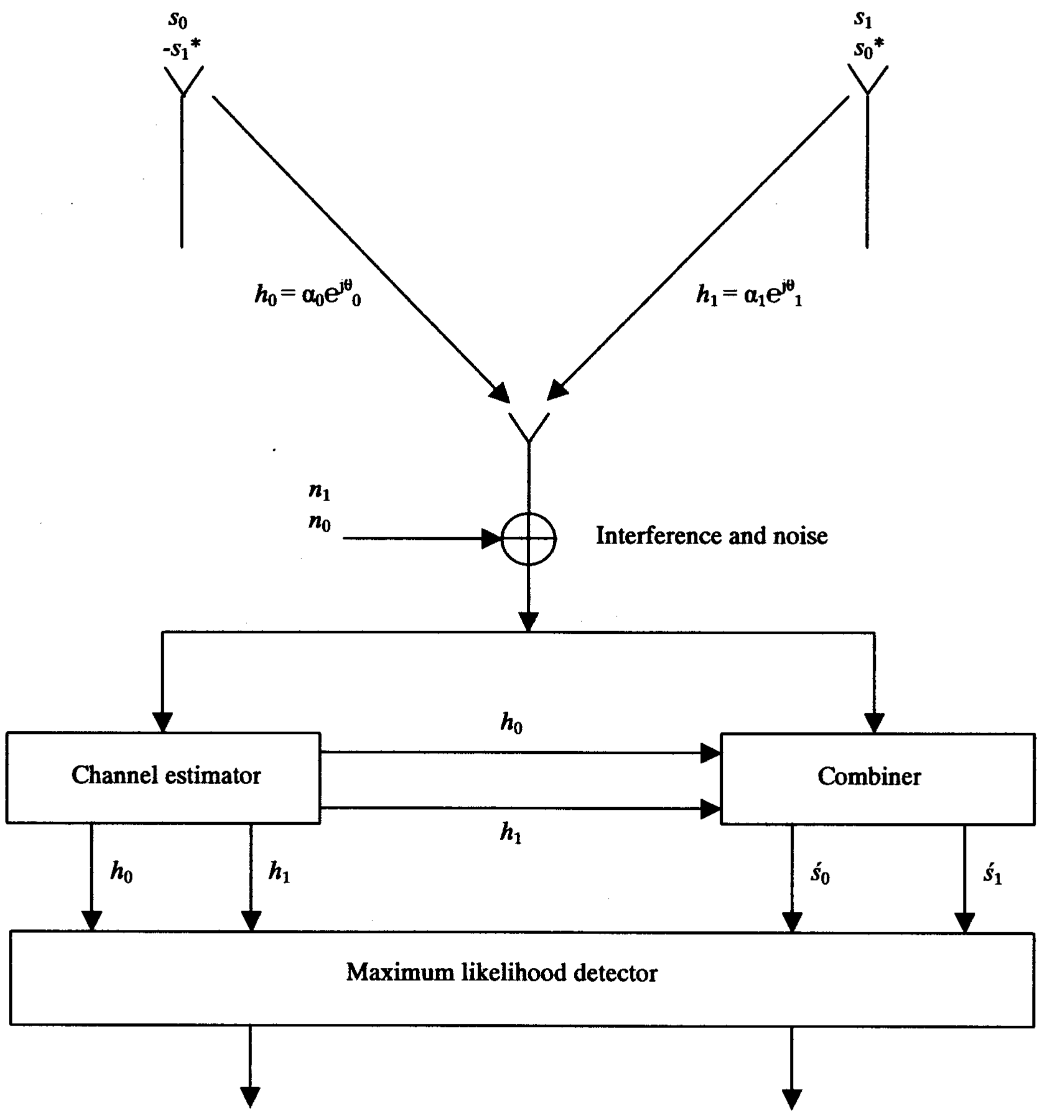


Figure 2.14 : The new transmit diversity scheme

2.6 Modulation

Most communication systems in use today are digital communication systems. Whether they work directly with digital data coming out of some type of computing device or the inputs are analog waveforms that are sampled and quantized, the end product to be transmitted over some arbitrary channel is digital data [12].

Most types of channels through which this data must travel, such as telephone wires, fiber optic cables, the atmosphere etc., have certain characteristics and constraints that force the transmitted data to occupy a particular band of frequencies, or bandwidth. In order to convert the digital data available at the source into a signal that can be efficiently transmitted through the channel the data goes through a process called modulation.

Modulation shifts the spectrum of the digital data, or baseband signal, in such way as to create a bandpass signal. A bandpass signal is one in which the signal spectrum is nonnegligible only about some frequency fc, called carrier frequency. For most systems, the carrier frequency is determined by a sinusoidal carrier waveform that is modulated by the baseband waveform to produce the transmitted signal.

A common method for accomplishing this is to take a stream of digital information at baseband, filter the waveform then mix it with a sinusoidal carrier [12]. The sinusoidal carrier, generated by an oscillator, serves to shift the frequency of the baseband waveform into a spectrum suitable for transmission over the channel of interest. Figure 2.15 shows a simplified communication system with no source or channel coding.

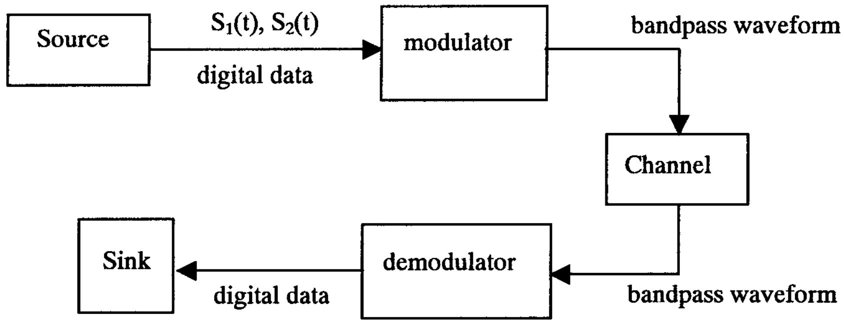


Figure 2.15 : Block diagram of an uncoded communication system.

2.6.1 Phase Shift Keying

In a coherent binary PSK system, the pair of signals, $s_1(t)$ and $s_2(t)$, used to represent binary symbols 1 and 0, respectively, are defined by

$$s_1(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.20)$$

$$s_2(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t + \pi) \quad = \quad -\sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t) \quad \ldots\ldots\ldots \quad (2.21)$$

where E_b is the transmitted signal energy per bit, T_b is the time duration and n_c is the integer number 1,2,3,... ... In order to ensure that each transmitted bit contains an integral number of cycles of the carrier wave, the carrier frequency f_c is chosen equal to be n_c / T_b for some fixed integer n_c. A pair of sinusoidal waves that differ only in a relative phase-shift of 180 degrees, as defined above, are referred to as antipodal signals. From the above equations, it is clear that there is only one basis function of unit energy, namely φ_1 (t).

$$\phi_1(t) \;=\; \sqrt{\frac{2}{T_b}}\cos(2\pi f_c t) \qquad 0 \le t < T_b \qquad \text{......................} \; (2.22)$$

Then we may expand the transmitted signals $s_1(t)$ and $s_2(t)$ in terms of $\varphi_1(t)$ as follows

$$s_1(t) \;=\; \sqrt{E_b}\phi_1(t) \qquad 0 \le t < T_b \qquad \text{..........................} \; (2.23)$$

and

$$s_2(t) \;=\; -\sqrt{E_b}\phi_1(t) \qquad 0 \le t < T_b \qquad \text{..............................} \; (2.24)$$

A coherent binary PSK system is therefore characterized by having a signal space that is one-dimensional (i.e. N= 1) and with two message points (i.e. M=2) [9] coordinates of the message points equal

$$s_{11} \;=\; \int_0^{T_b} s_1(t)\phi_1(t)dt$$

$$= \; + \; \sqrt{E_b} \qquad \text{...} \; (2.25)$$

and

$$s_{21} \;=\; \int_0^{T_b} s_2(t)\phi_1(t)dt$$

$$= \; - \; \sqrt{E_b} \qquad \text{...} \; (2.26)$$

2.7 Multiple Input Multiple Output (MIMO) Channels

Multi-antenna techniques are widely considered to be the most promising avenue for significantly increasing the bandwidth efficiency of wireless data transmission systems. In so called MIMO (multiple input multiple output) systems, multiple antennas are deployed both at the transmitter and the receiver. In MISO (multiple input single output) systems, the receiver has only one antenna, and the multiple transmit antennas are used for transmit diversity.

In order to analyze or discuss diversity techniques that involve the use of multiple antennas it is necessary to first understand the multiple input- multiple output (MIMO) channel model. Figure 2.16 represents the basic layout of a MIMO channel model. In the MIMO channel we no longer have a single input, rather, we have a vector of N input signals. At the output there is a vector of M output signals. The fading coefficients between transmit and receive antenna pairs it is necessary to use a N X M matrix, where $\alpha_{n,m}$ is the complex fading gain between transmit antenna n and receive antenna m. The last component to consider is the noise process, which is this case is also a vector. The noise is represented as a vector of M components, each of which is a sample of AWGN [12].

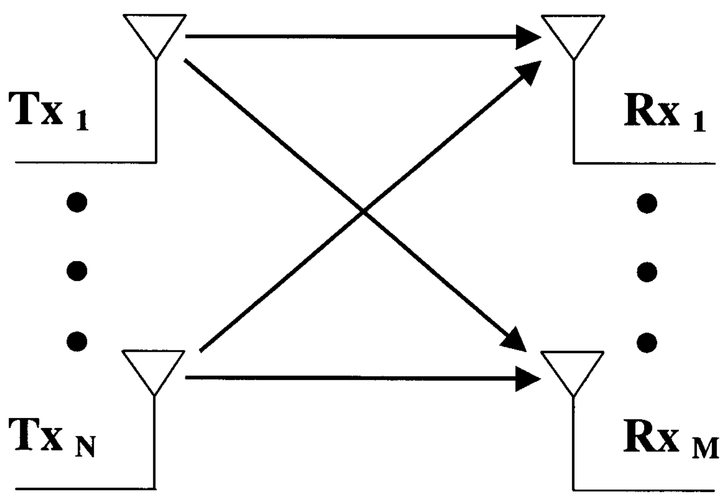


Figure 2.16 : Model of MIMO channel

The following shows the design of the input vector s, output vector r, noise vector n, and the fading coefficient matrix **H**.

$$s = [s_1\ s_2\ \ s_3\ \ldots \ldots\ldots s_N]$$

H =

$$n = [n_1\ n_2\ \ n_3\ \ldots \ldots\ldots n_m]$$

$$r = [r_1\ r_2\ \ r_3\ \ldots \ldots\ldots r_m]$$

The output is related to the input and the channel parameters by the following equation

$$\mathbf{r} = \mathbf{sH} + \mathbf{n}$$

2.8 Channel Coding (Hamming Code)

Codes that correct errors are essential to modern civilization and are used in devices from modems to planetary satellites. The theory is mature, difficult and mathematically oriented, but in this section we will describe only a simple and elegant code, discovered in 1949 [13].

Richard Hamming found a beautiful binary code that will correct any single error and will detect any double error (two separate errors). The Hamming code has been used for computer RAM, and is a good choice for randomly occurring errors. If errors come in burst, there are other good codes). Unlike most other error correcting codes, this one is simple to understand.

The Hamming code is a linear code. This means that if a and b are both codewords, then a + b is also a codeword. To check that this is true, note that w is a codeword if only if wH = 0 where H is the 3x7 matrix. If a and b are both codewords, then aH = 0 and bH = 0, so by the distributive law (a + b)H = 0. Linear codes are nice because they can be built from matrix computations. The bit stream to be encoded is broken up into blocks of length *k* which are mapped onto code words of length *n.* Linear if 1001011 and 0111010 are code words, and 1110001 is also code words too.

The codes use extra redundant bits to check for errors, and performs the checks with special check equations. A simple parity check will detect if there has been an error in one bit position. The Hamming code uses parity checks over of the position in block. The binary Hamming code is particularly useful because it provides a good balance between error correction (1 error) and error detection (2 errors).

2.8.1 How to detect and correct the error

In this section we will examine how transmission errors are detected and corrected by transmission control. We will first show how Hamming codes can be constructed to detect and correct one bit transmission error.
Let *k* be the length in bits of the character to transmit.

1) To detect transmission errors of up to m bits, the minimum number of (m+1) bits called "check bits" is needed.
2) To detect and correct transmission errors of up to *k* bits, the minimum number t of check bits is computed by:

$$2^{k+t} \geq 2^m\left[\binom{k+t}{0}+\binom{k+t}{1}+\ldots+\binom{k+t}{k}\right]$$

Thus, if we want to detect and correct 1 bit error in transmitting a character of length k bits, then we compute the minimum number t of check bits with m = 1 as follows:

$$2^{k+t} \geq 2^m\left[\binom{k+t}{0}+\binom{k+t}{1} = 2^k|1+k+t|\right]$$

That is,

$$t \leq \left|\frac{1}{2}(d_{\min}-1)\right|$$

Similarly, if a family of code words is chosen such that the minimum distance between valid code words is at least 3, then single bit error correction is possible. This distance approach is "geometric", while the above error bit argument is 'algebraic'. Either of the above arguments serves to introduce the Hamming code, an error control method allowing correction of single bit errors.

It was Hamming's ideas to use the sequence of parity checks to produce a syndrome. To illustrate the encoding process, a code with four message digits is chosen. We have already seen a (7,4) single error correcting rectangular code with three check digits and information rate 0.5 [13]. Using the idea of a syndrome we find that only three digits are actually needed.

The syndrome must take a value between one and seven to indicate the position of an error, or if no error has occurred. The Table 1 below illustrates the Syndrome Table.

Table 1 : The position and the syndrome

Position	Syndrome
4	100
2	010
1	001
6	110
3	011
7	111
5	101

The first parity check should produce the first digit of the syndrome (the 2^0 digit). Thus an error in this check restricts the final syndrome to one of the positions (values) 4,5,6,7 which are the only positions with 1 as their first digit. Hence the first parity check should be done on these positions. Similarly, the second parity check should check positions 2,3,6,7 and the third positions 1,3,5,7.

The parity checks must be independent which is no two check digits should check each other. To achieve that, Hamming placed the *i*th check digit in the 2^{i-1}th position. These, positions 4,2,1 have a single 1 in binary, which means they are only checked by the *i*th parity check.

Let's code the message 1010. The positions for the message digits are 6,3,7,5.

$$\begin{array}{ccccccc} 4 & 2 & 1 & 6 & 3 & 7 & 5 \\ \_ & \_ & \_ & \underline{1} & \underline{0} & \underline{1} & \underline{0} \end{array}$$

The first parity check over positions 4,5,6,7, is 0 +1+ 1 = 0 mod 2. So a 0 is placed in position 4.

4 2 1 6 3 7 5

0 _ _ 1 0 1 0

The second parity check is 0 + 1 + 1 = 0 mod 2. So a 0 is placed in position 2.

4 2 1 6 3 7 5

0 0 _ 1 0 1 0

The last check is 0 + 0 + 1 = 1 mod 2 and we place a 1 in position 1. The encoded codeword is 0011010.

To see that the syndrome actually indicates the position of an error, let H be the 3 X 7 matrix

$$H = \begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 & 1 \end{bmatrix}$$

whose columns are the binary numbers, 4 2 1 6 3 7 5. The 1's column is in positions 4,5,6,7, precisely the positions of the first parity check. Similarly, the second and third columns have 1's in the positions of the second and third parity checks respectively. Multiplying a codeword on the left by H is equivalent to perform the three parity checks. Let's check it on our codeword (0011010).

$$H = \begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 & 1 \end{bmatrix} X \begin{pmatrix} 0 \\ 0 \\ 1 \\ 1 \\ 0 \\ 1 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}$$

The zero syndrome indicates correctly that no error is present.

2.9 Present deployment of STBC

The demand for performance and capacity in cellular systems has generated a great deal of interest in the development of advanced signal processing techniques to optimize the use of system resources. In particular, much recent work has been done on space-time processing in which multiple transmit/receive antennas are used in conjunction with coding to exploit spatial diversity. As we know, space-time processing involves the exploitation of spatial diversity using multiple transmit and/or receive antennas and, perhaps, some form of coding. Recently, much of the work in this area has focused on transmit diversity schemes that use multiple transmit antennas. For example, a modified version of the STBC scheme developed by Alamouti [4] has been proposed by Texas Instruments [26] for the universal mobile telecommunication system (UMTS) and the third generation wideband CDMA (3G WCDMA) standards. The space-time processing could also enable 3G infrastructure to accommodate location technology in order to meet the requirements for E-911.

Since multipath fading affects the reliability of wireless links, it is one of the issues that contribute to the degradation of the overall Quality of Service (QoS). Diversity is an effective technique for mitigating the detrimental effects of deep fades. In the past, most of the diversity implementations have focused on receiver-based diversity solutions, concentrating on the uplink path from the mobile terminal

These combined signals are then sent to the maximum likelihood detector which, for each of the signals s_0 and s_1, uses the decision expressed for the modulation signals. PSK modulation is used for this simulation. It is because PSK has much higher spectral efficiency and power efficiency. The modulated signal can be differentially demodulated easily and the most advantage is PSK has constant envelope. In this project the bit rate is 1 bit/s/Hz, frequency carrier, *fc* = 3MHz, modulated frequency, *fm* = 3kHz, bandwidth = 30kHz and modulation index = 1.

At the receiver, the strongest signals according to the higher SNR and lower noise are found by using the selection method. The received signals are expressed as:

$$r = s + n$$

where r denotes the received signals, s denotes the transmitted signal and n denotes the noise signal. From the above equation, the noise between message A and message B are compared, and the lower noise is chosen. The Hamming Code is being used at the decoder.

As explained earlier, the space-time block code is defined by a N x M transmission matrixes which is a combination of the signals that will be transmitted, where N is the number of transmit antenna and M is the number of receive antenna. In this project, the (n,k) linear code is used, where n is the length of the code words and k is the number of bits in each uncoded message. In this project, n = 7 and k = 4. The Hamming code is used for this simulation, the reason is Hamming Code is a perfect code. We have 16 codewords in the Hamming (7,4) code as shown in Appendix D.

to the base station. Recently, more attention has been focused toward practical spatial diversity options for both base stations and mobile terminal [27]. One reason for this is the development of newer systems operating at higher frequency bands. For instance, the spacing requirements between antenna array elements for wireless products at 2.4GHz and 5GHz carriers do not significantly increase the size of mobile terminals. Dual-transmit diversity has been adopted in 3G partnership projects (3GPP and 3GPP2) to boost the data rate on the downlink channels because future wireless multimedia service are expected to place higher demands on the downlink rather than the uplink. This is the area where STBC technique is useful in particular implementation.

CHAPTER III

MATHEMATICAL SIMULATION

3.1 System Model

The system model that we will use to analyze the performance of space-time block codes with channel estimation errors is as illustrated in Figure 3.1.

The sequence of binary bits message is using uniformly distributed random numbers. The transmission sequence is given in Table 2, where *t* denotes the time, S denotes the symbol to be transmitted.

Table 2: Encoding and transmission sequence for 2-branch STBC

Antenna → / Time ↓	Antenna 1 (Message A)	Antenna 2 (Message B)
t	S_0	S_1
$t+1$	$-S_1^*$	S_0
$t+2$	S_2	S_3
$t+3$	$-S_3^*$	S_2

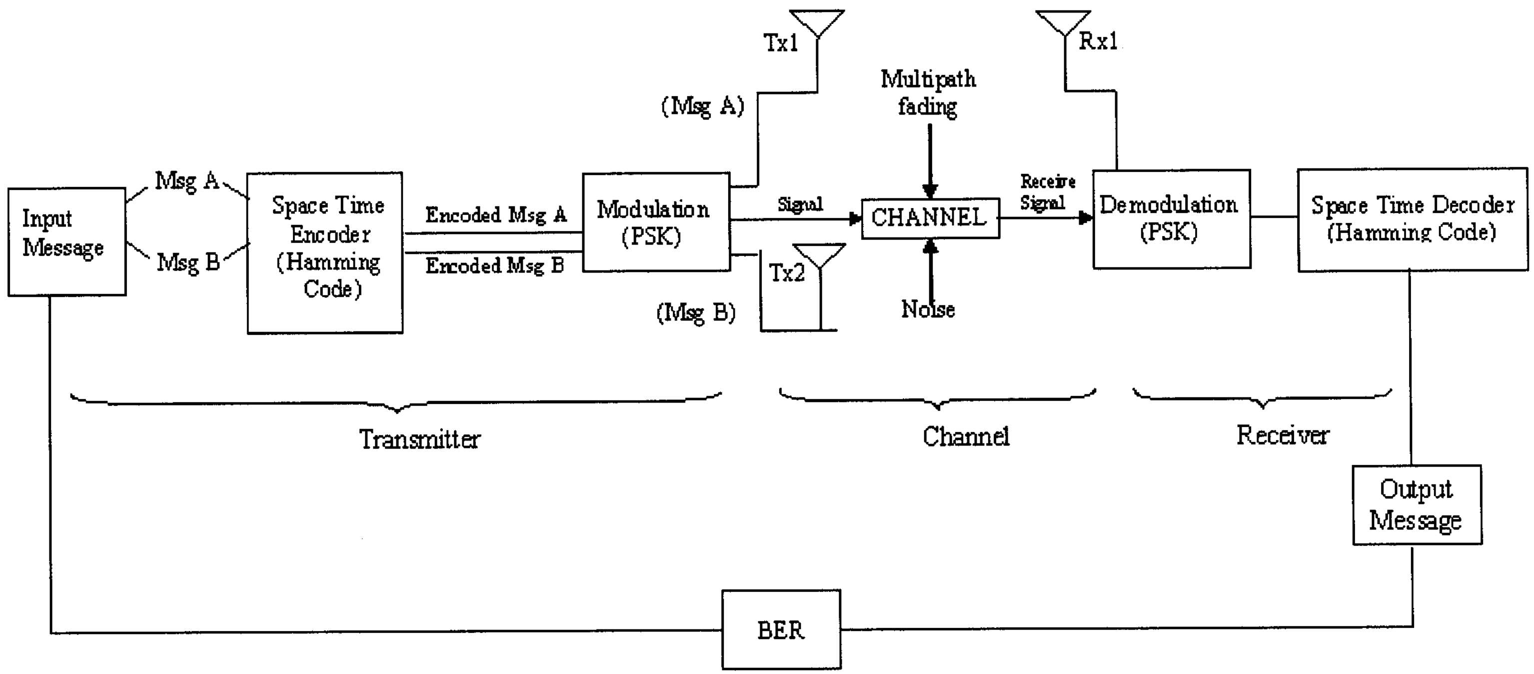


Figure 3.1 : System Model of STBC

This sequence is capable of full-rate transmission, meaning that two symbols are transmitted in four time slots using two antennas. The scheme provides a two-level diversity gain.

By assuming that the input message is 0110, as shown in Table 3

Table 3 : Input message

	S_3	S_2	S_1	S_o
Input message	0	1	1	0

As a time interleaving result, two different antennas transmit the messages as as shown in Table 4 below.

Table 4 : Message A and Message B

Message	S_O	$-S_1^*$	S_2	$-S_3^*$	Antenna No.
Message A	0	0	1	1	**Antenna 1**
	S_1	S_O	S_3	S_2	
Message B	1	0	0	1	**Antenna 2**

At a given symbol period, the two antennas simultaneously transmit two signals. At the first period, the signal transmitted from antenna 1 is denoted by S_o and the signal from Antenna 2 by S_1. At the next symbol period, signal $-S_1$ is transmitted from antenna 1, and signal S_o from antenna 2. This will be followed by S_2 transmitted from antenna 1, and S_3 transmitted from antenna 2. Lastly, signal $-S_3$ is transmitted from antenna 1 and signal S_2 is transmitted from antenna 2.

Space or spatial diversity technique is being used in the transmission. When space diversity is used, it is important that the electrical distance from a transmitter to each of its antennas and to a receiver from each of its antennas is an equal multiple of wavelengths long. This is to ensure that when two or more signals of the same frequency arrive at the input to a receiver, they are in phase and additive.

With space diversity, there is more than one transmission path between a transmitter and a receiver. Consequently, the probability of receiving an acceptable signal is higher when space diversity is used than when no diversity is used.

Assume that two transmit antennas are used at the base station to provide diversity at the remote station on the other side of the link. The important question is how far apart should the transmit antennas be to provide diversity at the remote receiver. The answer is that the separation requirements for receive diversity on one side of the link are identical to the requirements for transmit diversity on the other side of the link. This is because the propagation medium between the transmitter and the receiver in either direction are identical.

To provide sufficient decorrelation between the signals transmitted from the two transmit antennas at the base station, it is essential to have on the other of ten wavelengths of separation between the two transmit antennas. Equivalently, the transmit antennas at the remote units must be separated by about three wavelengths to provide diversity at the base station.

For the combining scheme, the combiner shown in Figure 2.1 builds the following two combined signals that are sent to the maximum likelihood detector;

$$s_0 = h_0 r_0 + h_1 r_1$$
$$s_1 = h_1 r_0 + h_0 r_1$$

3.2 Simulation Tool (Matlab Version 6.1)

To start the programming, we must type the filename in the Matlab command window

>> *test*

where *test* is the M-file. Here, Matlab Translater will run the programme from the file line by line. In this project the filename is PSKber.m (refer Appendix B)

The Hamming code relies on algebraic fields that have 2^m elements. Some functions in this toolbox use a primitive polynomial to determine the primitive element. To reduce the mathematical background, use the default parameters in commands that ask for primitive polynomials. For more specific use encode, decode and hammgen (Hamming generator).

In this project, the block coding technique is Hamming and the parameter is under Primitive polynomial and List of Galois Field Element. The process of encoding a message into $[n,k]$ linear block code is determined by a k-by-n generator matrix G (genmat). Specifically, the 1-by-k message vector v is encoded into the 1-by-n codeword vector vG. If G has the form $[I_k\, P]$ or $[P\, I_k]$, where P is some k-by-$(n-k)$ matrix and I_k is the k-by- k identity matrix, then G is the standard form. Encoding a message using a generic linear block code requires a generator matrix. Define the variables as msg, n, k and genmat. Encodes the information in msg using $[n,k]$ code that the genmat determines.

Decoding the code requires the generator matrix and possibly a decoding table. Decode the information in code, using the $[n,k]$ code that the generator matrix genmat determines. Decode also corrects errors according to instructions in the decoding table that *trt* represents. (see Appendix D). A decoding table tells a decoder how to correct errors that may have corrupted the code during transmission.

Hamming codes can correct any single error in any codeword. This toolbox represents a decoding table as a matrix with n columns and 2^{n-k}. Each row gives a correction vector for one received codeword vector. A Hamming decoding table has $n+1$ rows. The syntable (refer Appendix D) function generates a decoding table for a given parity check matrix. The biterr (bit error rate) function compares unsigned binary representations of elements in row with those in column.

3.3 Simulation Development of STBC

This project employs two transmit antenna and one receive antenna (N=2, M=1). Encode modulation symbols are S_0, S_1, S_2 and S_3. The time t is time diversity. The message S_0, S_1, S_2 and S_3 are four symbols to be transmitted. At time t, S_0 and S_1 are simultaneously transmitted, then at the next symbol period, $t + 1$, $-S_1^*$ and S_0 are simultaneously transmitted. The message sequence of the simulation is shown in Table 5.

Table 5: Message sequence for STBC

Antenna → / **Time ↓**	**Antenna 1 (Message A)**	**Antenna 2 (Message B)**
t	S_0	S_1
$t + 1$	$- S_1^*$	S_0
$t + 2$	S_2	S_3
$t + 3$	$- S_3^*$	S_2

For antenna 1 (message A) the symbols of S_0, $-S_1^*$, S_2 and $-S_3^*$ are transmitted and for the antenna 2 (message B) the symbols are S_1, S_0, S_3 and S_2 are transmitted.

Table 6 below elaborate the message and encoding message with time diversity.

Table 6: Message and encoded message

Message Word	S_0 S_1 S_2 S_3	0 1 0 0
Message A	S_0 $-S_1^*$ S_2 $-S_3^*$	0 1 1 1
Message B	S_1 S_0 S_3 S_2	0 0 0 1
Encoding Message A	-	0 0 1 0 1 1 1
Encoding Message B	-	1 0 1 0 0 0 1

3.4 Development of Hamming Code

In this project consider the example of (7,4) linear block codes that have the following parameters: $d_{min} = 3$. The block length , $n = 2^m - 1 = 2^3 - 1 = 7$. The number of message bits: $k = 2^m - m - 1 = 2^3 - 3 - 1 = 4$. And the number of parity bits: $n - k = m = 7 - 4 = 3$.

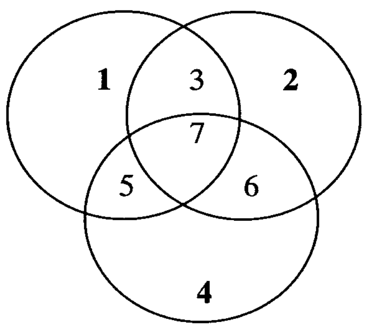


Figure 3.2 Message bit and parity check bit representative

Figure 3.2 represents the message bit and the parity check bits. The (1,2,4) are parity check bits and the message are (6,3,7,5). The code word for Hamming code represents the (4,2,1,6,3,7,5) bit [15]. From the example as shown in the previous section, if the message sent is 0100, the message A is 0010 (according to the theory received at one antenna). For encoding, the message A 1110010, which is equivalent to 4216375 (as mention in previous chapter). The position of the parity check bit can be checked as follows.

Position	Message
4	5 7 6 = 0 1 0 = 1
2	3 7 6 = 1 0 0 = 1
1	3 7 5 = 0 1 0 = 1

The parity check bit for message A is 111. And the encoded message A is 1110100.

The following matrix represents an appropriate generator matrix for 7,4 hamming code:

$$G = \begin{bmatrix} 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 1 \end{bmatrix}$$

The corresponding parity check matrix is given by:

$$H = \begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 & 1 \end{bmatrix}$$

If [G] x [H] = 0 (no error occur) if [G] x [H] $\neq$ 0 (error)

To detect error for hamming code, assuming that we receive message B, R = [0110110]

Syndrome = H X R

$$= \begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 & 1 \end{bmatrix} X[0110110]$$

= [111]

From the syndrome table as shown in Table 7, the syndrome 111 represents the error pattern, e = 0000010. The error pattern will exclusive OR (XOR) with receive signal to get the transmit codeword, C. ($C = R \oplus e = 0110100$). From the transmit codeword, the message is 0100 and the parity check bits is 011.

Table 7 : The syndrome and the error pattern

Syndrome	Error pattern
000	0000000
00	1000000
010	0100000
001	0010000
110	0001000
011	0000100
111	0000010
101	0000001

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Flowchart of Simulation

This section will explain briefly the flowchart of the simulation process of this project (refer to Appendix A and C for the output result of Matlab Version 6.1 programme). Figure 4.1 shows the flowchart of the simulations.

In this project the input message, $k = 4$ and the codeword, $n = 7$. The input message will have the time interleaving process.

In this case, when coding is added, the code redundancy allowed the receiver decoder to correct the errors so that the decoded output is almost error free. However, in some applications, large wide pulses of channel noise occur. If the usual coding techniques are used in this situation, bursts of errors will occur at the decoder output because the noise bursts are wider than the "redundancy time" of the code. This situation can be ameliorated by the use of code interleaving.

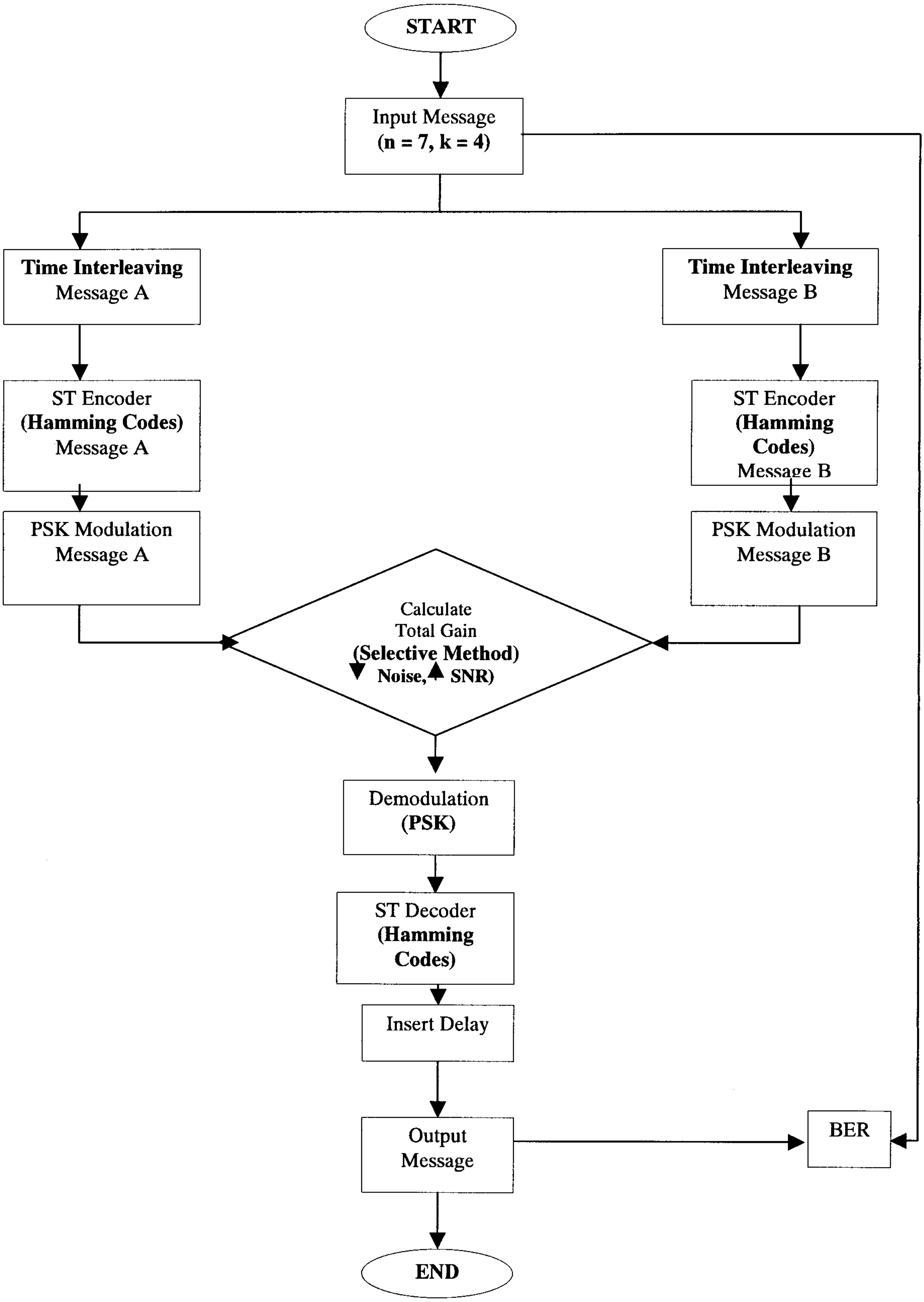


Figure 4.1: Flowchart of Simulation

Message A and message B are encoded by using Hamming code for error control process. The messages length will change from a 4 bits message to a 7 bits codeword and modulated by using PSK as the technique of modulation. The modulated message will then be changed from digital to analog form through the modulation process.

The receive messages is then calculated based on the total gain. By using the selective method the message are chosen block by block. At the receiver, the strongest message is chosen based on higher Signal to Noise Ratio (SNR) and lower noise. The message is demodulated by using coherent PSK and the message is changed from passband to baseband form. The demodulated messages are then decoded by using Hamming code as the linear block decoding technique.

The first step in the decoding of a linear block code is to calculate the syndrome for the received message. If the syndrome is zero, there are no transmission errors in the received message. If the syndrome is non-zero, then the received message contains transmission errors that require correction.

In the case of a Hamming code in systematic form, the syndrome can be calculated easily. The decoded message is converted from a 7 bits codeword to a 4 bits message and the time interleaving will be performed. Therefore, the output message will be produced. We need to compare the output message with the input message to get the value of Bit Error Rate (BER).

4.2 Results from the simulation

The system model consists of transmitting, channel and receiving process. All result for the process are obtained from the programming of Matlab Version 6.1. The transmitting process includes the input signal, message time interleaving, encoding process and modulating process. At the channel we introduced multipath Rayleigh fading. The receiving process included the demodulating process, decoding process and time deinterleaving process.

Finally, we analyzed the performance of BER using different techniques of diversity; a system of STBC and MRC technique.

4.2.1 Input message

For a (7.4) code, there are four information or message bits and three parity bits. From the simulation programme, k = 4 and n = 7.

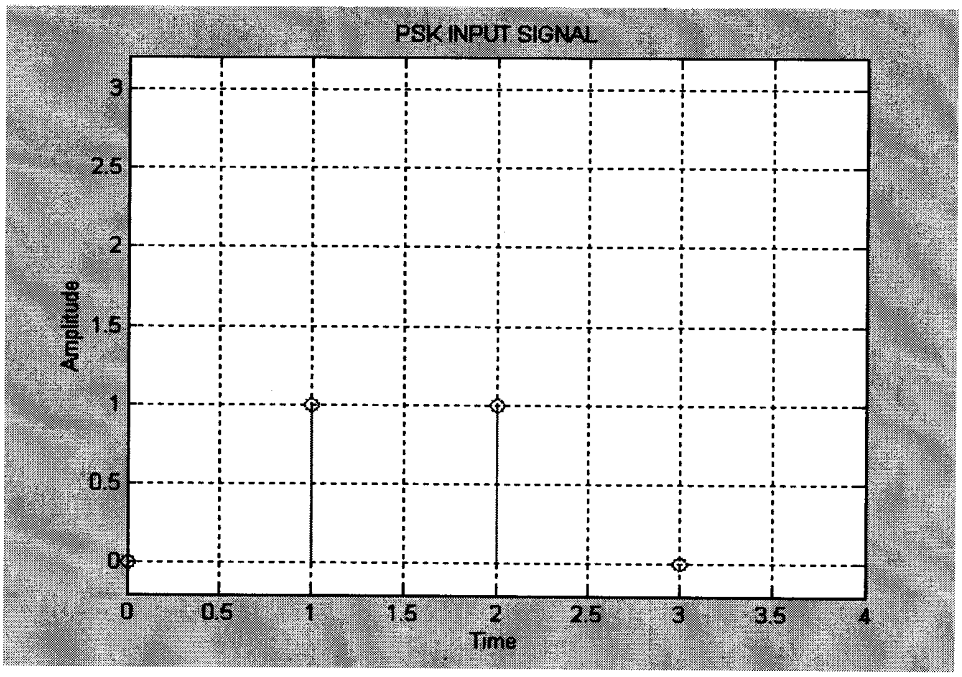


Figure 4.2: Transmitting Process For Input Signal [0110]

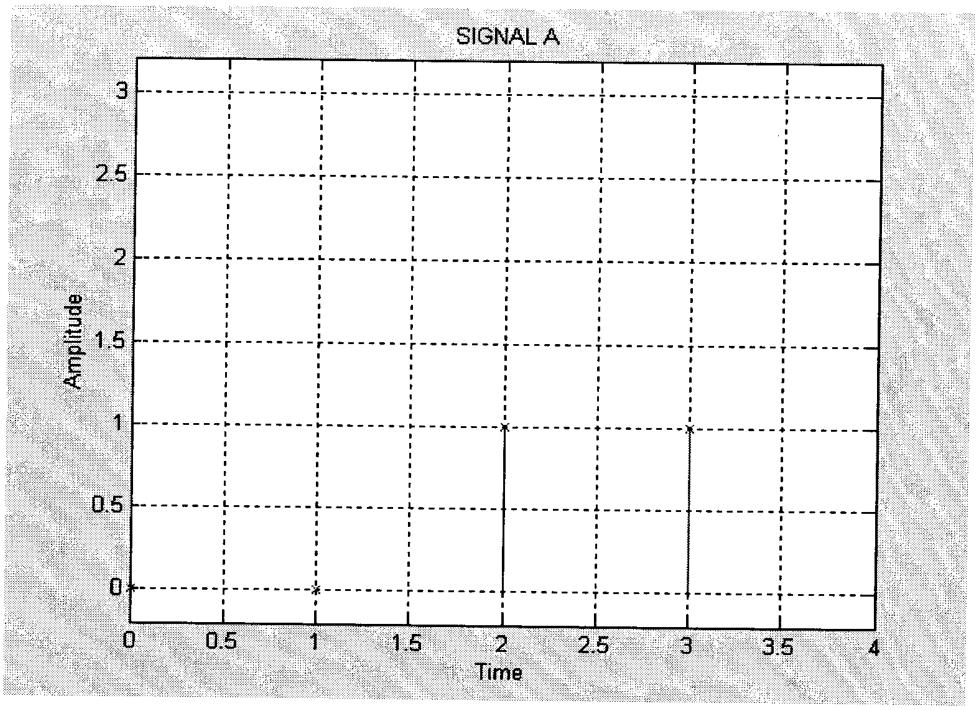


Figure 4.3 : Time Interleaving Message For Signal A [0011]

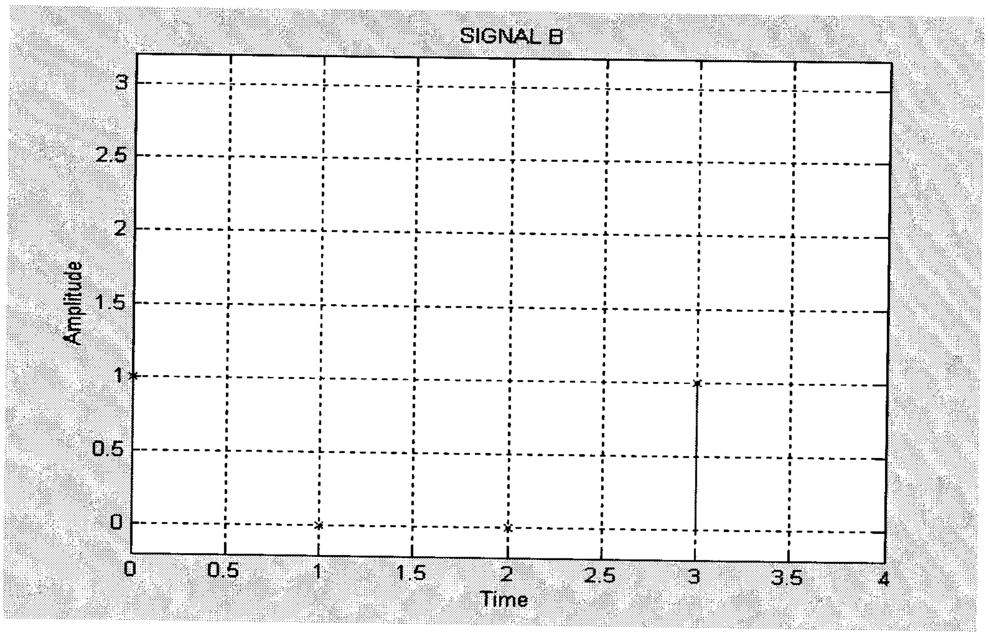


Figure 4.4 : Time Interleaving Message For Signal B [1001]

From Figure 4.2, the input message is 0110. The input message has been separated into two, Signal A and Signal B according to time interleaving encoding process as shown in Table 3. Figure 4.3 and 4.4 show the input message for signal A and B respectively.

4.2.2 Encoded message

Encoding is done in spatial and time. Message A and message B are encoded using Hamming codes. For the encoding process, the messages will change from 4 bits codeword to 7 bits codeword (consisting of 4 message bits, 3 parity bits). Figure 4.5 shows the encoding process for message A is 0100011. This is taken from the time interleaving message for message A.

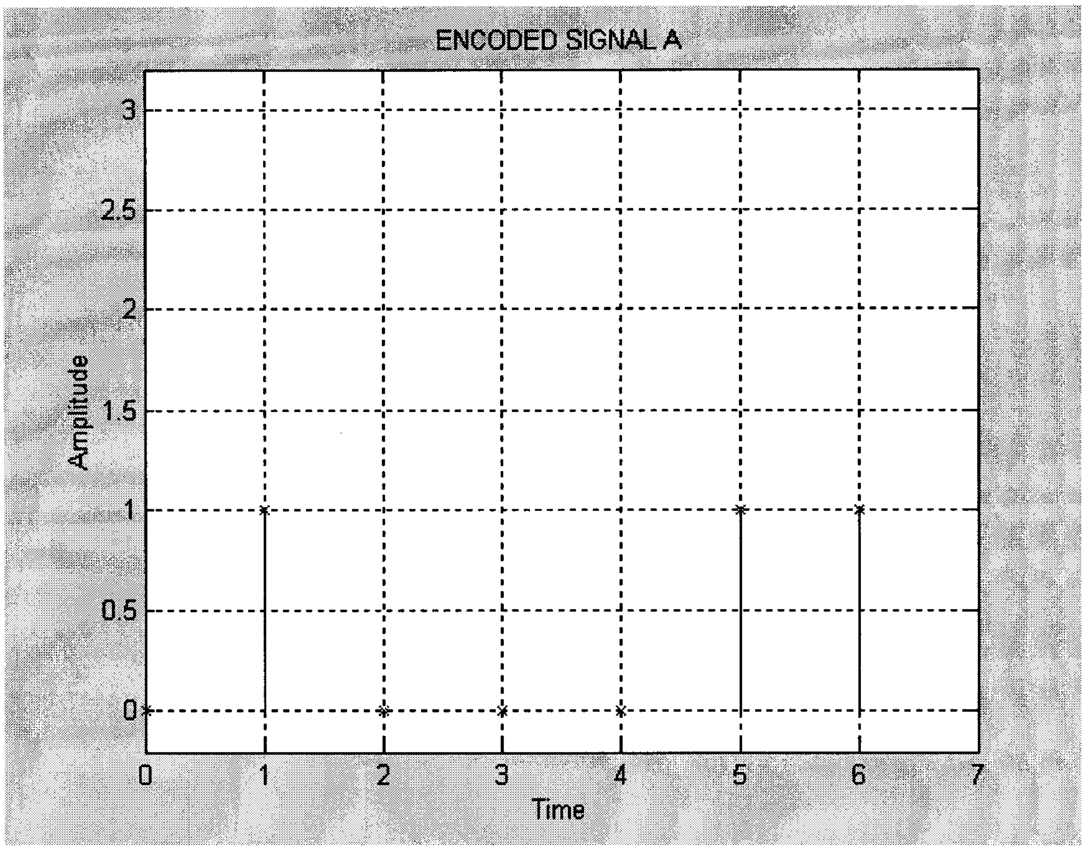


Figure 4.5: Encoding Process For Message A [0100011]

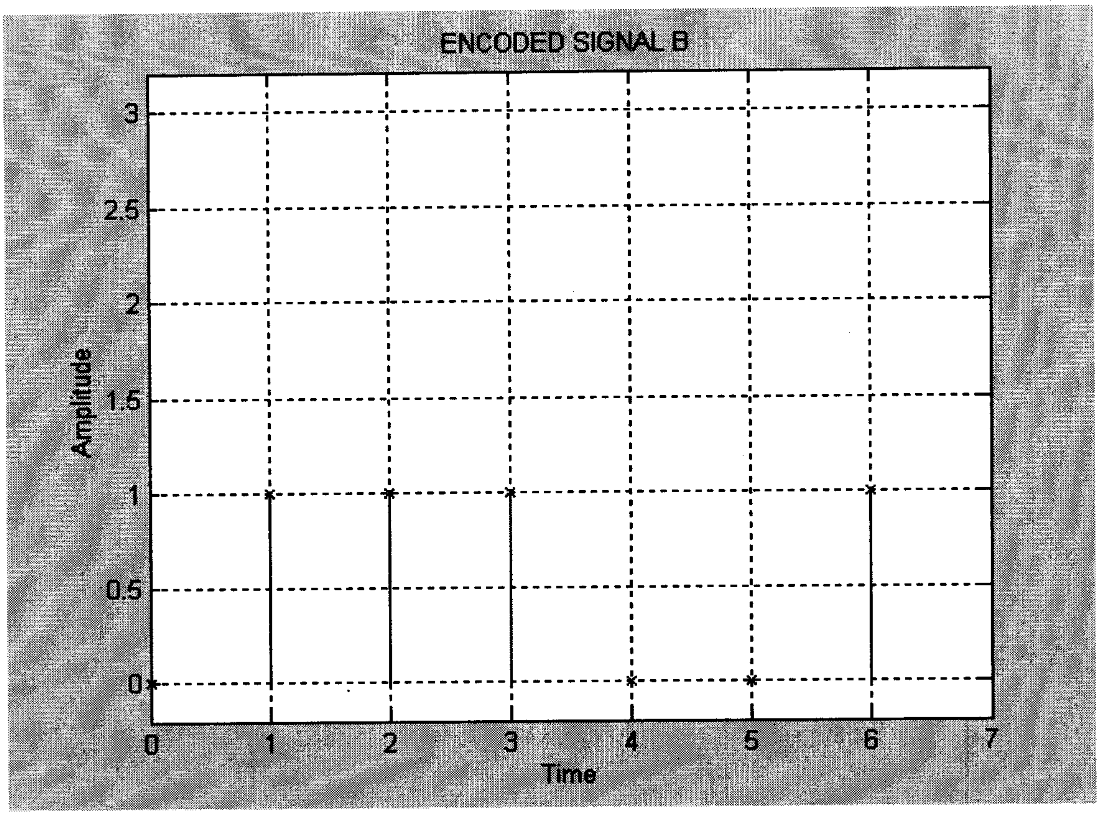


Figure 4.6: Encoding Process For Message B [0111001]

Figure 4.6 shows the encoding process for message B is 0111001. This is taken from the time interleaving message for message B.

4.2.3 PSK Modulated Signal

PSK signal has a constant envelope and amplitude. PSK also does not require the frequency of the carrier be shifted as with the FSK system. Instead, the carrier is directly phase modulated, which means the phase of the carrier signal is shifted by the incoming data. The modulation index for PSK is 1.

The passband carrier frequency, *fc* is chosen to be 3MHz. In this project, coherent PSK is used. It has much higher spectral efficiency and power efficiency. The modulated signal also can be differentially demodulated easily. Furthermore, PSK provides a low probability of error, so it can be used economically when the message is sent simultaneously and on the same carrier frequency. The decoding delay is only 2 symbol period. In this project, the value of symbol period, *Ts* is greater or equals to *(1 / fc)*.

$$T_s \geq \left(\frac{1}{f_c}\right)$$

PSK is not susceptible to the noise degradation and bandwidth limitations. This means smaller variations in the signal can be detected reliably by the receiver. From this project the modulated signal for message A = 0100011 (refer to Figure 4.7) and modulated signal for message B = 0111001 (refer to Figure 4.8) have a continuous phase signal.

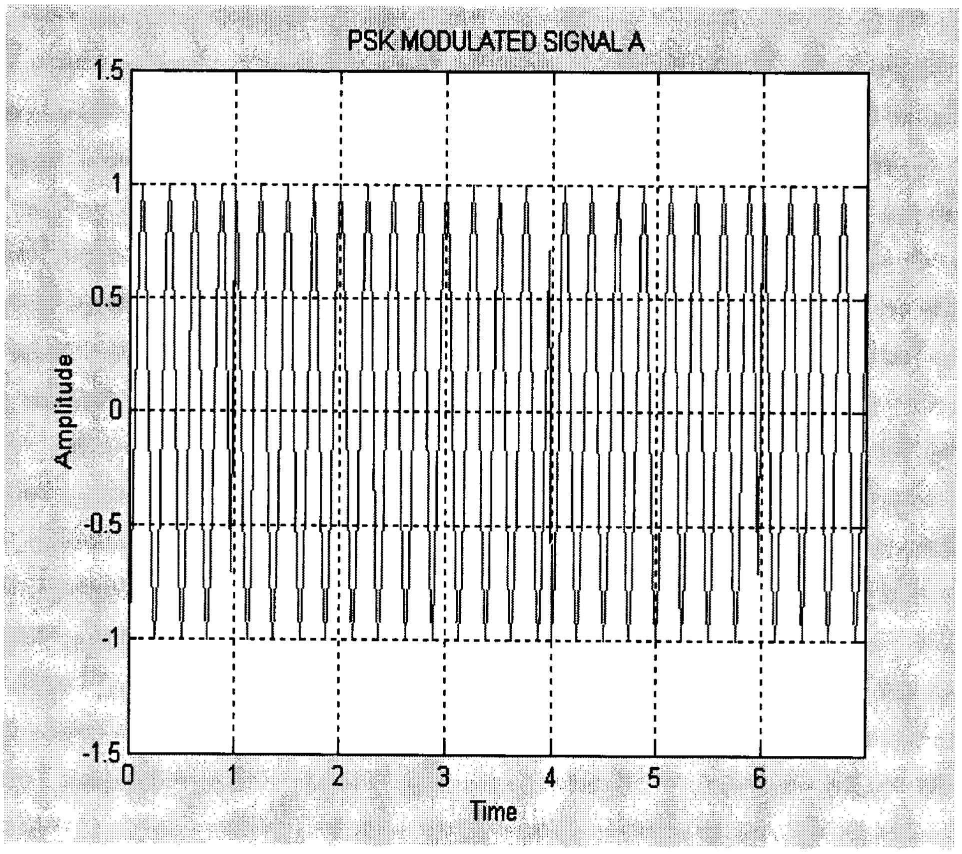


Figure 4.7: Modulating Process For Message A [0100011]

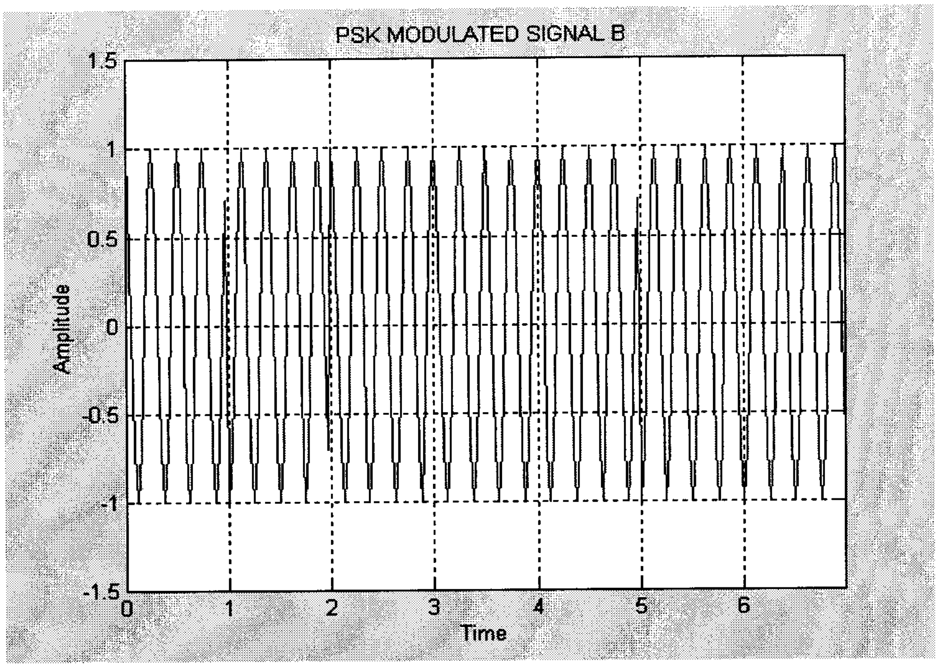


Figure 4.8: Modulating Process For Message B [0111001]

At a given symbol period, two signals are simultaneously transmitted from the two antennas. The signal transmitted from antenna one is denoted by s_0 and from antenna two by s_1. During the next symbol period, signal ($-s_1$) is transmitted from antenna one, and signal s_0 is transmitted from antenna two.

The separation requirements for receive diversity on one side of the link are identical to the requirements for transmit diversity on the other side of link. This is due to the propagation medium between the transmitter and receiver in either direction being identical.

To provide sufficient decorrelation between the messages transmitted from the two transmit antennas at the base station, we must have on the order of ten wavelengths of separation between the two transmit antennas.

Equivalently, the transmit antennas at the remote units must be separated by about three wavelengths to provide diversity at the base station. In this project, we use carrier frequency, fc = 3 MHz, so the wavelength is 100 meter and the distance between two transmitter antenna is 10 meter. The calculation is as follows:

$$\lambda = \frac{\text{speed of lights}}{fc}$$

$$\lambda = \frac{3 X 10^{8}}{3 X 10^{6}}$$

$$= 100 \text{ meter}$$

The distance between two transmitter antenna

$$L = \left(\frac{1}{10}\right) X \lambda$$

$$L = \left(\frac{1}{10}\right) X 100$$
$$= 10 \text{ meter}$$

4.2.4 Multipath Rayleigh Fading

The BER also increases greatly when there is Rayleigh Fading, in contrast to its behavior in a Gaussian environment. For the reason multipath fading in the received antenna, which results in a higher BER, must be reduced.

Figure 4.9 and Figure 4.10 shows the Multipath Rayleigh Fading for Message A and Message B at the channel. As seen from the Figure 4.7 and Figure 4.8, the signals distorted are larger in amplitude variation on signal A and signal B due to fading channel because of Multipath Rayleigh Fading.

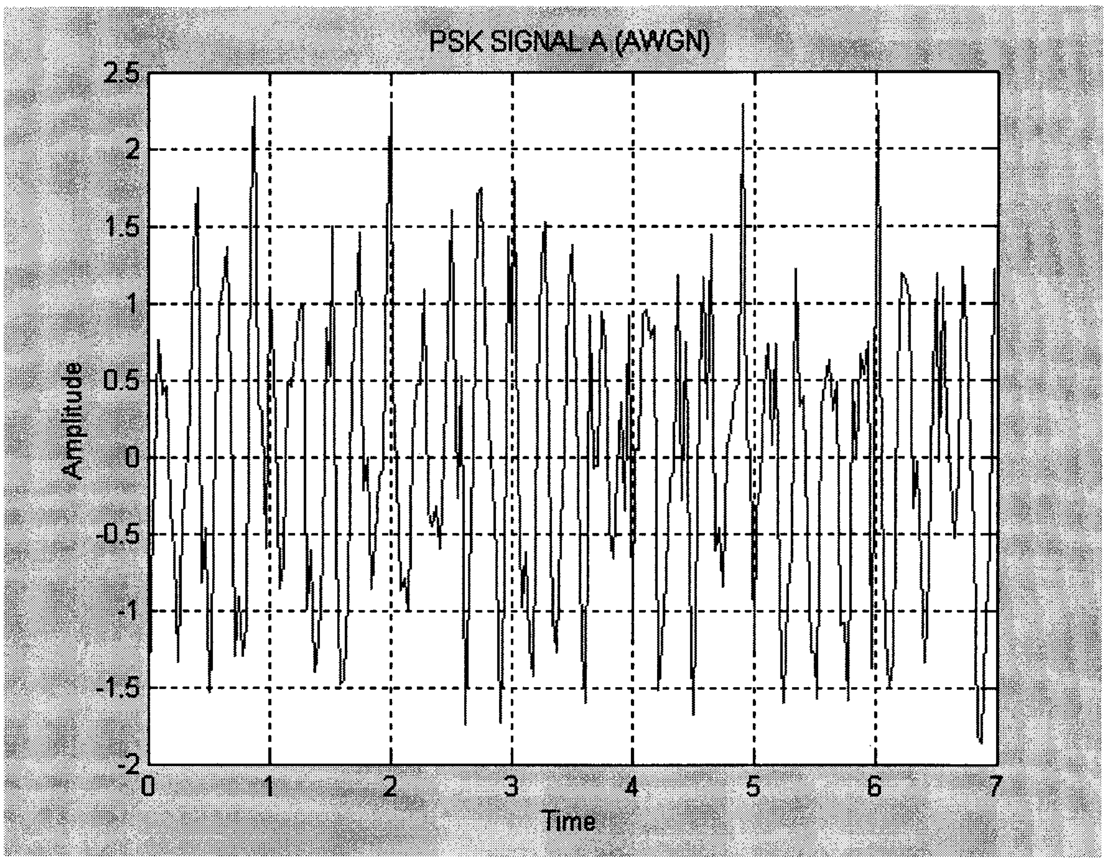


Figure 4.9: Signal Message A with Multipath Rayleigh Fading

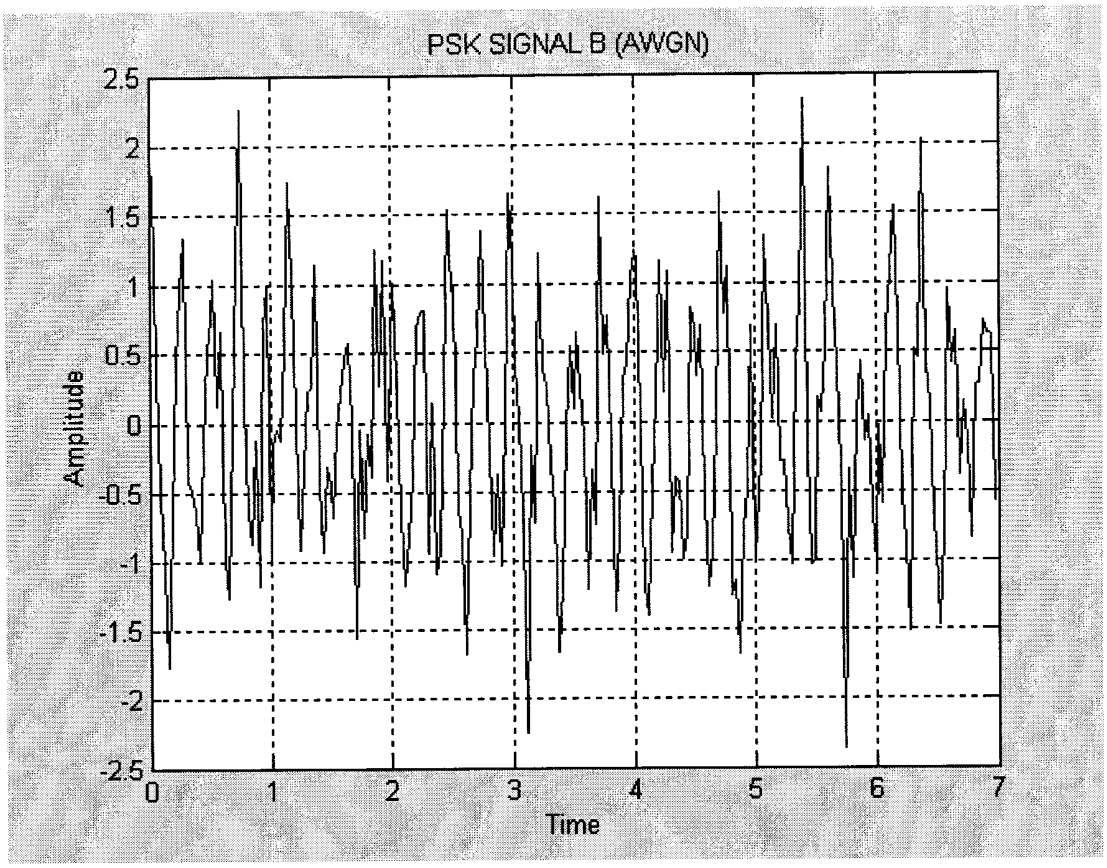


Figure 4.10: Signal Message B with Multipath Rayleigh Fading

4.2.5 PSK Demodulated Signal

For this project, we only use one receive antenna. The receiver antenna will choose the strongest message based on the higher SNR, this is conducted a block by block basis and using a selective method. The receive message is demodulated by using the coherent PSK technique. Demodulation is the process of converting sinusoidals to digital data. In this case, it is found, message B has the strongest signal level. Therefore, the demodulated message B = 0111001 is chosen as shown in figure 4.11.

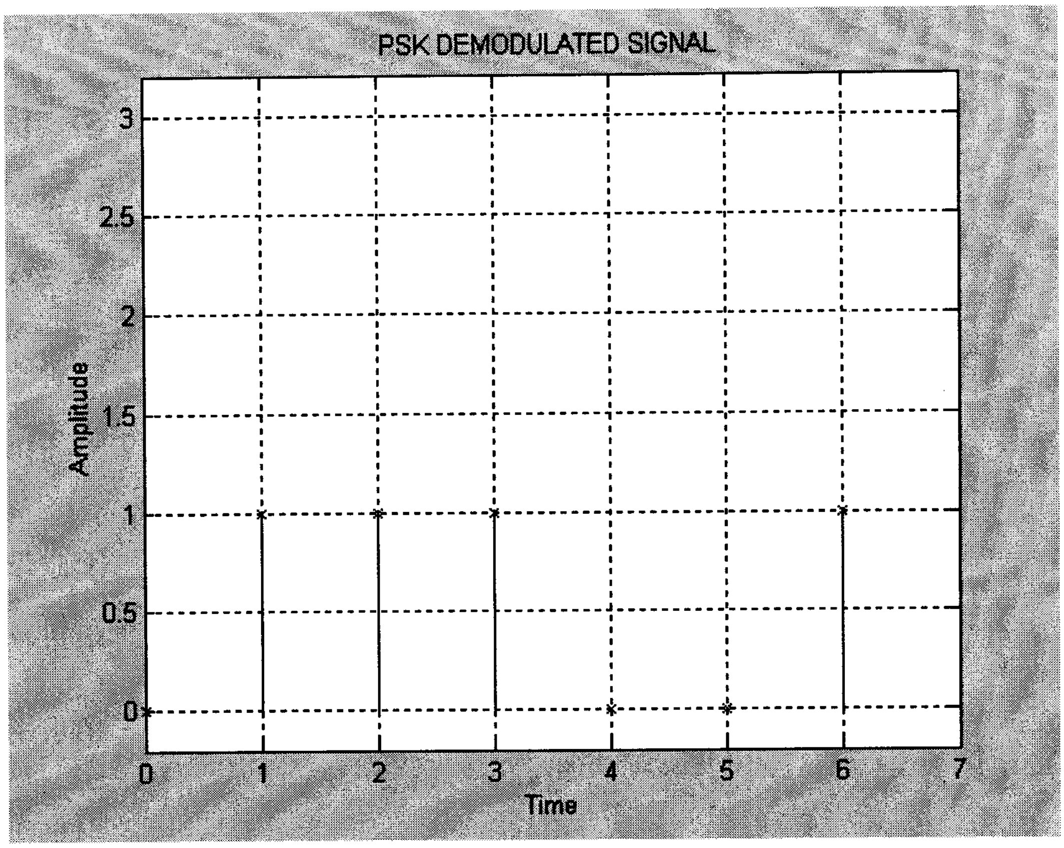


Figure 4.11 : Receiving Process (Demodulated Signal)
Signal Message B [0111001]

4.2.6 Decoded Signal

The demodulated message is decoded by using Hamming Codes. During the decoding process, a syndrome is calculated. We recall that the first step in the decoding of a linear block code is to calculate the syndrome for the received message.

In the case of a Hamming Codes in systematic form, the syndrome can be calculated easily. To detect error for hamming code, assuming that we receive message R = [0110110], is as follows

Syndrome = H X R

$$= \begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 & 1 \end{bmatrix} X [0110110]$$

= [111]

Referring to Table 6, when the syndrome is 111, the error occurs at s_1 and value for error pattern, e = 0000010. The error pattern will exclusive OR with receive signal to get the transmit codeword, C. (C = R $\oplus$ e = 0110100). From the transmit codeword, the message is 0100 and the parity check bit is 011.

To check the error, the new transmit message will exclusive OR with the original transmit message. In this case, the error is corrected because the value for error correction is 0000000. The message is decoded to produce 4 bits message and message B = 1001 is obtained.

The decoded message = 1001 will generate the time deinterleaving process (referring to Table 2) to produce the output message = 0110 as shown in figure 4.12.

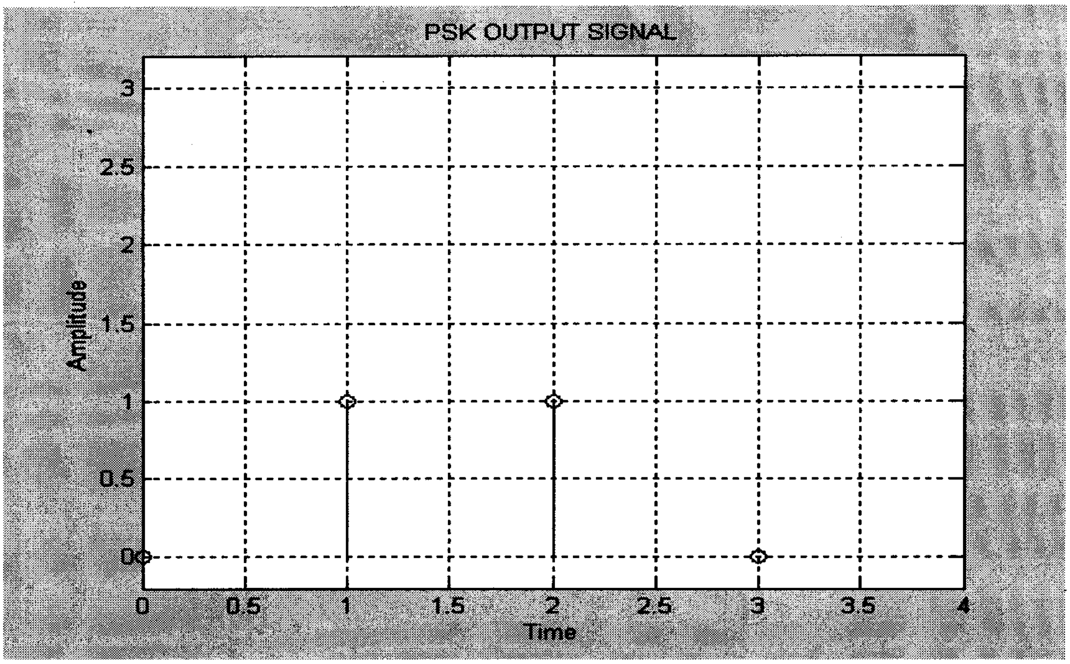


Figure 4.12: Output Message [0110]

By comparing the input message and the output message, the value of BER can be calculated.

At the transmitter process, the input signal is separated into two messages according to time interleaving process. (Refer Table 2).

4.2.7 BER Performance of STBC using PSK

The performance of BER in this project is for a simple transmit diversity scheme. It improves the signal quality at the receiver by simple processing across two transmit antennas at the transmitter.

In this project, we apply linear block coding technique , which is one of the techniques of STBC. Applying a linear block coding technique using Matlab Version 6.1, a comparison of the performance of BER by using Maximum Ratio Receive Combining (MRRC) technique and linear block coding technique for PSK is shown in Figure 4.6. Figure 4.6 presents the simulated performance for *N* = 2 transmit antennas, together with the maximum ratio reference curve.

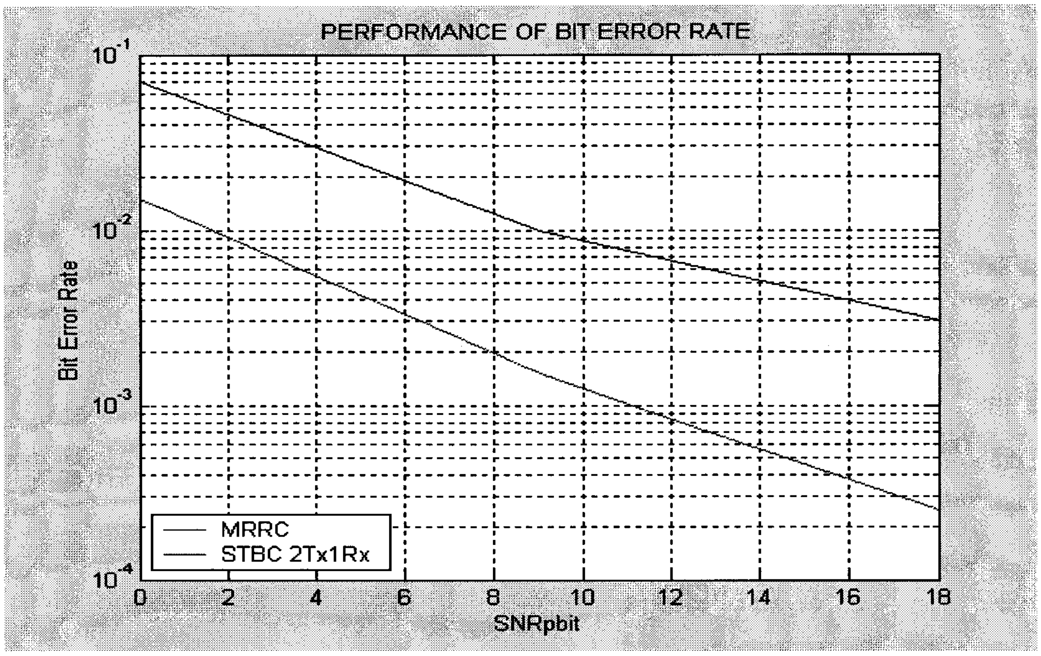


Figure 4.13 : The BER performance comparison for 2 Tx X 1Rx antenna of coherent PSK with MRRC and STBC Technique in multipath Rayleigh fading

As shown in Table 8 below, when the SNRpbit (db) = 1 dB, the BER for Maximum Ratio Combining at N=2 equals to 0.07 and PSK ST simulation equals to 0.0150.

At 10dB, bit error rate (BER) for Maximum Ratio Combining equals to 0.01 and PSK ST simulation equals to 0.0015.

The BER for STBC using PSK simulation equals to 0.0003 and Maximum Ratio equals to 0.003 when SNRpbit equals to 19 dB. At the 19 dB, STBC using PSK has a better performance compared to Maximum Ratio Combining, whereby the difference of BER is equal to 0.0027.

The results show that the simulated performance of STBC using PSK when N=2, by using linear block coding technique provides a better performance gain compared to the Maximum Ratio Receive Combining technique when N=2 for STBC even though the simple algorithm is applied. From the results, it shows that the performance of BER has improved by thirty three percent (33)%.

Table 8: Performance of BER (N=2)

SNRpbit (dB)	MRRC BER (N=2)	PSK ST Simulation BER (N=2)
1	0.07	0.0150
10	0.01	0.0015
19	0.003	0.0003

4.3 Effect of Space Time Block Coding

As mention earlier, the most effective technique to mitigate multipath fading in a wireless channel is to use a transmitter power control. If channel conditions as experienced by the receiver on one side of the link are known at the transmitter on the other side, the transmitter can predict the signal in order to overcome the effect of the channel at the receiver.

Other effective techniques are temporal and frequency diversity. Time interleaving or diversity, together with error correction coding can provide diversity improvement. The signal quality at the receivers can be improved by simply block encoding across the multiple antennas at the transmitter. At a given symbol period (*Ts*), two signals are simultaneously transmitted by the two antennas.

From the obtained result, the use of multiple antennas at both the transmitter and receiver is essential for the STC concept to work effectively, since STC exploits both the temporal and spatial dimensions for the construction of coding designs which effectively mitigate fading (for improved power efficiency) and are able to capitalize upon parallel transmission paths within the propagation channel for improved bandwidth efficiency). The probability of receiving an acceptable signal is higher when space diversity is used.

The principle of diversity is to provide the receiver with several replicas of the same signal. Diversity techniques improve the performance of radio signals without any increase in the transmitted power. Diversity techniques work best when the different replicas of the signal are transmitted through independent fading multipath channels.

Signal combining is a very important part of a diversity system. With transmitter diversity, the total power is divided between the different branches. Correlation between the different branches reduces the diversity gain. Power imbalance between the different branches reduces the diversity gain.

CHAPTER V

CONCLUSION & RECOMMENDATION

5.1 Conclusion

In this project, the concepts of transmit diversity and the use of STBC in a multipath fading channel has been evaluated. In addition, we could see the performance difference between STBC and MRRC system through the simulation made. Using two transmit antennas and one receive antenna, this scheme provides the same diversity order as MRRC technique.

The result analysis showed that the STBC give better BER performance compared with maximum-ratio receiver combining (MRRC) method. By adding the channel coding (in this case is Hamming code), the result indicates that the BER performance can be improved by selectively adding redundant information into the transmitted data stream. It can allow the receiver to detect and correct an error during the transmission.

From the results obtained, it can be concluded that space–time block coding is clearly a simple and elegant method for transmission using multiple transmit antennas in a wireless environment. This codes has a very simple maximum-likelihood decoding algorithms which is only based on linear processing. The multiple transmit antennas used to combat time-varying fading and to mitigate interference. This diversity scheme produce a delayed replica of the transmitted signal to be re-transmitted through a second, spatially independent antenna and both signals are coherently combined at the receiver end by a channel equalizer. Each data symbol in the block can be decoded separately by minimizing the correct metric. Furthermore, the scheme seems to be a superb candidate for next generation wireless systems, as it effectively reduces the effect of fading at the remote units using multiple transmit antennas at the base stations.

5.2 Recommendation for future work

Future work may extend in different directions which may include the following :

(1) The space-time block coding is still not satisfied to be confident as suitable method for the real wireless communication since the wireless communication channel may experience frequency selective fading/CSI channel. Therefore, the study for the space-time block coding in the frequency selective fading is needed for the future work.

(2) The comparison between the block code and the other existed code like Turbo code will be interesting, and combine STC with other transforms such as OFDM to achieve better performance. In this project the receive signal is not adding with the channel matrix, so in the next future work I suggest that the channel matrix H should be included in the received signal to give better understanding of the real performance.

(3) In this project, the study is mostly focusing on the implementation of space-time block coding in mobile network. The multiple antennas proposed is based on two transmit antenna and one receive antenna system. Implementation of space-time block coding in other system such as modem, wireless LAN & broadband wireless could be possible. As the kind of system requires high data rate transmission, its performance over a frequency-flat Rayleigh fading channel should be studied. The multiple antennas at both transmitter and receiver can be deployed.

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